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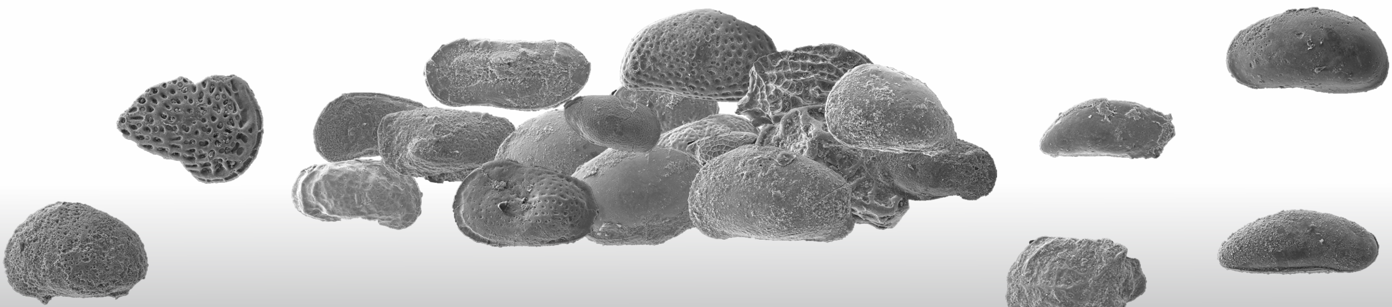

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Structural overview of eastern Slovenia

Eastern Slovenia is a structurally complex region, the result of over 50 million years of vigorous tectonic activity in a varied succession of tectonic phases. The region is an internal part of the broad Eurasia-Africa collision zone, northeast of the triple junction between the Eurasian lithospheric plate, the Adria microplate and the Pannonian lithosphere (Schmid et al., 2008, 2020). The Pannonian basin was an area of extensional tectonics throughout much of the Neogene, through rifting, lateral extrusion of the Eastern Alps, subduction, slab roll-back and break-off in the Carpathians and the associated lithospheric thinning, followed by thermal subsidence of the area. Extensional tectonics are reflected structurally in a series of extensional and transtensional basins along graben and half-graben systems, and a thinned crust across the entire region, with the MOHO at only approximately 25-30 km depth. A thick succession of Neogene syntectonic and post-tectonic sediments records the tectonic evolution of the region and its sedimentary environments.

The northeastern part of Slovenia is structurally dominated by a large-scale Neogene extensional tectonics which resulted in the formation of a metamorphic core complex, and a number of sedimentary basins. The metamorphic core complex comprises the Pohorje and Kozjak domes, in which the metamorphic rocks outcrop at the surface and the Murska Sobota extensional block, buried under a kilometer of Neogene and Quaternary sediments, which formed along the Kozjak, Pohorje and Bajan detachments. A number of basins formed along the detachments and higher-order normal faulting that presumably soles to the detachments at depth, including the Mura-Zala Basin, the Slovenj Gradec Basin, the Radgona Subbasin, Ljutomer Subbasin and the Ribnica-Selnica Trough (Fodor et al., 2001; Fodor et al., 2021), the latter also known as the Haloze-Ljutomer-Budafa Subbasin (Fodor et al., 2001). Extensional tectonics persisted until the Sarmatian, after which the entire region underwent thermal subsidence, which resulted in the deposition of a further, post-tectonic succession of sediments (Fodor et al., 2002). Neogene sediment thickness reaches up to approximately 3000 m in the Radgona Subbasin and over 5000 m in the Ljutomer Subbasin (Gosar, 2005). The southeastern part of Slovenia, south of the Periadriatic Fault System and the northernmost edge of the Mid-Hungarian Zone, the Balaton Fault also underwent extensional Neogene tectonics as evidenced by the structure in the Krško Basin (Poljak, 2017), where the asynchronous Raka and Globoko Basins reach depths up to 1500 m.

A regional stress field and tectonic inversion occurred in the Pliocene, resulting in E-W to ENE-WSE resulting compressional structures. In NE Slovenia normal faulting was reactivated as reverse to transpressive faults, including the North and South Haloze Faults and the Ljutomer Fault (Atanackov et al., 2021), with associated large-scale folding, including the Ormož-Selnica Anticline and smaller-scale folds, such as the Petišovci Anticline. These structures form the NW extreme part of the Mid-Hungarian Zone and represent the W-most extension of the Balaton Fault. No significant active faulting occurs north of this line. Part of the regional shortening is taken up by the dextral strike-slip faults of the Periadriatic Fault Sytem and the Mid-Hungarian Zone, most importantly the Šoštanj Fault, Labot / Lavanttal Fault and the Donat Fault. All these faults are active, with estimated slip rates on the order of 0.5-1 mm/yr (Atanackov et al., 2021). South of the Periadriatic Fault System, delineated by the Sava and Šoštanj Faults, the regional compression resulted in the formation the Sava Folds (Placer, 1998). This is a fold and thrust belt of E-W to ENE-WSW trending large scale folds. Formation is post-Sarmatian in the north (Placer, 1998) and post middle-Pannonian in the south (Poljak, 2017). The folds are confirmed to be active in the south-southeastern part of the Sava Folds. The area is also part of heightened seismicity, with moderate seismicity rates and moderate historic earthquakes, the largest of which is the 1917 Brežice earthquake with Mw ~5.5-6 (Grünthal et al., 2013; ARSO, 2020).

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Changes in ostracod assemblages: a case study from the Miocene deposits of the North Croatian Basin

During the last twenty years, a comprehensive investigation of non-marine and marine ostracod assemblages has been performed on Miocene samples from the North Croatian Basin (NCB). NCB belongs to the south-western margin of the Central Paratethys, and its evolution is connected to the Miocene global sea level changes and the connection with the Mediterranean Sea.

Here we present the main results of the ostracod investigation. The Miocene ostracods are crucial in biostratigraphy, paleobiogeography, and paleoenvironmental reconstruction. According to the previously established ostracod biozones (Jiříček and Říha, 1991; Sokač, 1972), the determination of the biozones for Miocene stages is enabled. Clearly defined biozones can be easily correlated to the other regional basins of Paratethys and the Mediterranean. Ostracod biozonation gives the best results for the Badenian, Sarmatian, and Pannonian marine and brackish deposits (Hajek-Tadesse and Prtoljan, 2011; Grizelj et al., 2023; Mužek et al., 2023); while biozonations of non-marine Early and Middle Miocene deposits are difficult due to endemic ostracod development (Hajek-Tadesse et al., 2009, 2023; Hajek-Tadesse, 2020).

Ostracods are excellent tools for precisely and clearly distinguishing non-marine, marine, and brackish environments and barely noticeable environmental changes. In marginal transitional environments, ostracods are used primarily as hydrodynamics and salinity indicators, and ostracod species can first document possible exchanges between lakes and seas. The composition of non-marine ostracod assemblages from the oldest Early/Middle Miocene lake deposits depends mainly on the salinity and depth of the lake water. According to the ostracod species, the first marine ingression into the lake in NCB was registered (Hajek-Tadesse et al., 2009, 2023; Mandic et al., 2019; Marković et al., 2021).

Deep marine ostracods are best preserved and richest in lower Badenian, while in upper Badenian and Sarmatian, the number of deep-water ostracods decreased, and the number of shallow-water ostracods increased. Finally, at the beginning of the Sarmatian-Pannonian Extinction Event, ostracod fauna changed from marine to endemic Pannonian brackish assemblages.

Considering the species' paleobiogeography, the presence of "migrated ostracod species" in Miocene deposits of NCB can detect an open connection with a wider area of Central Europe and the Dinaride Lake System in the Lower Miocene; the Mediterranean Sea and the Indian Ocean in the Middle Miocene; and to the different Basins of Lake Pannon and the Paleo-Mediterranean during the Late Miocene.

This research was conducted in the scope of the internal research project „ Development of Miocene paleoenvironments in Croatia and their connection with global events (RAMPA) at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia."

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"Old-new" concepts of stratigraphy, geodynamics and paleogeography of the Vienna Basin - based on re-evaluation of data from its northern part (Slovakia)

More than a hundred years of the geological research at the Alpine-Carpathian junction area yielded extensive datasets, however, accompanied by multiple concepts of stratigraphy geodynamics and paleogeography, which were/are sometimes contradictory. The diverse depositional systems of the Vienna Basin, including alluvial, deltaic, littoral and offshore marine sediments bear information about the age, sedimentary environment, tectonics, paleogeography, climate, sea level changes, and about the time-varying connections of the Central Paratethys towards the World´s Ocean. A re-evaluation of the available results from the northeastern part of the basin, located in Slovakia, substantially relying on petroleum research data, should support some of the existing hypotheses and, on the contrary, disprove the insufficiently supported ones.

A significant advance in our proposed concept of biostratigraphy is omitting the formerly widely used lithostratigraphic correlations based on benthic taxa, which include inherently diachronous paleoecological zones (e.g., Lagenidae or Agglutinated foraminiferal zones). The documented shelf-slope clinoforms, present in the Karpatian, Badenian, Sarmatian and possibly Pannonian successions, represent an important feature of the basin fill, which is a strong indication of the migration of the depositional system across the accommodation space at a given time. Diachronic boundaries of the lithostratigraphic units can therefore be expected. However, verification of this hypothesis in the future requires a detailed sequence-stratigraphic investigation and accurate geochronological data.

The Lower Miocene sediments documented in the northern Vienna Basin represent a remnant of a larger basin system, which formed in compressive to transpressive tectonic regime. Depocenters of this wedge-top basin developed between the advancing front of the neo-Alpine accretionary wedge and backstop, formed by the paleo-alpine consolidated units of the orogene. The Eggenburgian onshore marine deposits of the Dobrá Voda Mb. and the offshore "schlier" of the Lužice/Čausa fms., are overlain by the Ottnangian transgressive Chropov and Veterník mbs., passing to the "schlier" of Cunín Mb. of the Lužice Fm. The Ottnangian Planinka Fm. includes material derived from the paleo-Alpine consolidated Central Western Carpathians.

During the Karpatian, the basinal, deep-water, "schlier" of the Lakšárská Nová Ves (LNV) Fm. deposited. Source of the sandy Týnec Mb. documents local uplifts of the accretionary wedge ribbons. The deltaic Jablonica Fm. polymict conglomerates source area were the Western Carpathians, in contrast to the Aderklaa Fm. derived from the Eastern Alps. Riverine sediments of this formation pass towards the north into the deltaic Šaštín Sand Mb., situated at the base of the Závod Fm. The late Karpatian accelerated subsidence led to deposition of the Prietrž Mb. turbidites of LNV Fm. At the Lower/Middle Miocene boundary, the sea level fall led to formation of incised valleys. The Kúty Fm. is regarded as the earliest Badenian canyon fill, although some authors include them to the Karpatian.

The sedimentary record of the wedge-top basin is genetically unrelated to the subsequently opened Middle and Late Miocene grabens, half grabens, and elevations of the actual Vienna Basin, formed in a trans-tensional to extensional tectonic regime. The synrift subsidence rate varied laterally across the basin. The re-shaping of the drainage network resulted in formation of a large delta system along the SW, W margins of the basin. The Malé Karpaty horst structure began to be uplifted along the eastern margins, feeding the basin with coarse clastic sediment supply.

The Early Badenian rifting included the Kúty Fm. lowstand, transgression and highstand of the Lanžhot Fm., together with the Devínska Nová Ves Fm. The Late Badenian rifting sequence included the lowstand of the onshore Žižkov Fm. and offshore Jakubov Mb., transgressive littoral Stupava Fm., followed by highstand offshore Studienka Mb. of Hrušky Fm., passing to the normal regressive deltaic Matzen Fm. The Sarmatian rifting included basal, terrestrial Kopčany and Radimov mbs., basinal transgressive to regressive Holíč Fm. and deltaic Skalica Fm. representing the highstand normal regression. The supposed Late Miocene rifting with Lake Pannon transgression accumulated the lacustrine Bzenec Fm., followed by highstand normal regression of the deltaic Čáry and alluvial Gbely fms.

Although the global sea-level changes are to some degree traceable in the Vienna Basin fill, as its depositional environments were connected with the surrounding seas across the basins of the Alpine and Carpathian Foredeep and along a Trans-Tethyan Trench Corridor between the Eastern Alps and Dinarides. The ultimate eustatic impact on the basin sedimentary record is frequently overwhelmed by local tectonics and by changes in sediment supply. Besides the Early and Middle Miocene marine connections of the Central Paratethys towards the World´s Ocean across the Mediterranean, well established in the scientific community, we are considering a possible contact between the Central and Eastern Paratethys (Transcarpathian Trench Corridor). Based on the obtained results this seaway was likely active at the Early–Middle Miocene boundary, or in the latest Kozakhurian - the earliest Tarkhanian regional stage (16–15 Ma).

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The legacy of the Tethys Ocean

The Paratethys Sea, a vast anoxic water body, played a pivotal role in the geological and environmental history of Central Eurasia during the Neogene period. Originating from the remnants of the Tethys Ocean, this extensive sea significantly influenced the regional climate and geography.

During the Neogene, Paratethys underwent dynamic changes in connectivity, alternating between full marine conditions and evaporitic crises. These shifts led to the deposition of a variety of sediments, including marine molasses, evaporites, and continental-lacustrine materials. Eventually, the sea evolved into a massive megalake, filling with clastic sediments from surrounding mountain ranges. This transformation was a critical phase in shaping Central Eurasia's paleogeographic and paleoenvironmental landscape, underscoring the impact of marine connectivity on the region's depositional environments over time.

The variable landscape and environments of the Paratethys Sea played a crucial role in shaping the climate, ecosystems, and even human evolution in Eurasia and beyond. The fluctuating conditions of this extensive water body created diverse habitats, fostering unique biological communities and influencing regional climate patterns over geological timescales. As Paratethys transitioned from an anoxic sea to a sprawling megalake, it not only shaped the physical geography but also served as a critical ecological and climatic buffer. These environmental shifts likely influenced the floristic and faunal dispersal patterns and adaptation strategies, highlighting the profound interconnectedness between Earth's geological evolution and the development of its inhabitants. Understanding ancient environments like Paratethys is vital for grasping the broader context of Earth's history.

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Miliolidae dominant assemblages in Central Paratethys: implications for Middle Miocene sediments

During the Neogene, the connection between newly developed Mediterranean Sea and the Paratethys, as well as among individual basins, became unstable (Rögl, 1999). The isolation of Paratethys caused the formation of endemic fauna and divided it into the extensive Eastern Paratethys and the smaller parts of Western and Central Paratethys (Báldi, 2006; Piller et al., 2007). The Central Paratethys includes the Pannonian basin system and extends from the foreland of the East Alpine Basin of lower Austria to Moldova (Seneš, 1961).

The aim of this work is to study middle Miocene sediments with predominance of miliolids from the Central Paratethys. Our study attempts: A) to determine the reason for the predominance of miliolids in these sediments; B) to compare standard methods with new geochemical methods, and C) to determine the paleoenvironmental conditions during this period. Miliolidae are well known for specific environmental requirements, living conditions, substrates and for different salinity and oxygen-level tolerance (Sen Gupta, 2003).

For this study we collected samples and data from several localities of Serravallian age (Dumitriu et al., 2017; Šarinová et al., 2018; Babejová-Kmecová et al., 2022) with horizons of predominance of miliolids (Vienna Basin – borehole cores Rohožník 112, Poddvorov 96 and 118, Suchohrad 63, MZ 102, MZ 93 and MZ 34; Danube basin – borehole ŠVM 1 and Ivanka 1; East Slovakian Neogene Basin – borehole Albinov 4, Polish Carpathian Foredeep Basin - Jamnica M-83, Machów; Eastern Carpathian Foreland Basin - FH3P1 Rădăuţi core section, Dorneşti outcrop, Costeşti section, and Central Anatolian Basin - Tuglu section). The methodology was based on laboratory work, LA-ICP-MS analyses (element/Ca ratios, MZ 102) and the statistical methods using the programs R (R Development Core Team, 2016) and PAST – Paleontological Statistics version 4.10 (Hammer et al., 2001). The foraminifera assemblages were integrated into morphological epiphytes groups (B, C and D; Langer, 1988) and infauna (Murray, 2006). The composition of trace elements in foraminifera calcite (Mg/Ca, Mn/Ca, Ba/Ca) were measured in the most abundant miliolid species: *Articulina problema*, *Varidentella rotunda*, *Pseudotriloculina consobrina*, *Siphonaperta lucida* and one hyaline species *Porosononion granosum*.

Our study defined three great environmental groups with different sample composition and two smaller groups. The first group is defined by 51% of infaunal species preferring brackish-hypersaline lagoons, estuaries, and inner shelf with occasional suboxia/anoxia. The second major group is represented by over 67% (from which 14% are EP-C, P. *granosum*) of epifaunal species and epiphytes inhabiting marine-hypersaline lagoons to shelf. The third group is represented by significant dominance (97%) of epifaunal epiphytic species living in marine-hypersaline shallow lagoons to inner shelf preferring oxic conditions. The analysis of the shells from MZ 102 is also showing changes of the dissolved oxygen in the water column, as well as changes in salinity. These results are comparable to those using standard methodology.

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Sarmatian and Pannonian nannofossil assemblages from the SW margin of the Central Paratethys

The Kozjansko area belonged to a marginal SW part of the Central Paratethys with sedimentation taking place between the Kiscellian and the Pannonian (Aničić et al, 2002). A 1500 m Miocene sedimentary sequence was studied for nannofossils and ostracods.

The ostracod assemblages from the lower part of the section are of lower Sarmatian age, while those from the upper part indicates Pannonian age. Nannofossil assemblages from the lower part of the section can be placed into standard nannoplankton biozones NN6, NN7 and, possibly, NN8, while the correlation of the Pannonian assemblages with standard nannofossil biozones is difficult due to endemic developments.

The oldest determined nannofossil assemblages belong to the biozone NN6 spanning the Late Badenian and Early Sarmatian. The age was determined on the basis of the absence of *Spenolithus moriformis,* common specimens of *Calcidiscus pataecus* (acme reported in NN6 just above the Badenian/Sarmatian boundary across the Central Paratethys (e.g. Galović, 2020)), the presence of *Helicosphaera walbersdorfensis*, large form of *Reticulofenestra pseuboumbilicus* and the elliptical form of *Coronocyclus nitescens*. A few individual specimens of *Discoaster kugleri*, marker of the biozone NN7, have been detected in a short interval in the middle part of the section (samples IM-12H to IM-12K). The genus *Catinaster*, marker of the biozone NN8, was not observed. While the last common occurrence, and LO of *Coccolithus miopelagicus* and the LO of *Helicosphaera walbersdorfensis*, which are used to approximate NN7/NN8 boundary (e.g. Galović, 2020) were detected, we cannot correlate the upper part of the Sarmatian succession with NN8 as the Sarmatian/Pannonian boundary is assigned an age of 11.6 Ma (Piller et al., 2007) within NN7.

The Sarmatian is usually interpreted as a time of lowered salinity and brackish conditions in the Central Paratethys and the study area (Aničić et al, 2002). Contrary to this established view, the studied Sarmatian assemblages are diverse and consistent with marine environment. The constantly present and occasionally common ascidian spicules, belonging to stenohaline tunicates (Łukowiak et al., 2016) support the fully marine character of the studied Sarmatian deposits as well.

Samples from the top of the Sarmatian succession were barren of nannofossils, which possibly reflects a sea-level lowstand at the Sarmatian/Pannonian boundary corresponding to the situation observed in the Vienna Basin by Kovač et al. (2018).

In agreement with studies from other Paratethyan Pannonian sites (Chira et al., 2021; Čorić 2021; Galović, 2020), Pannonian nannofossil assemblages from Imenska gorca contain endemic species, which were observed here for the first time in Slovenia. I*solithus semenenko* and *Planolithus eggeri* appear first (prominent in samples IM-19 to IM 28) along with the genus Praenoelaerhabdus. In turn they are replaced by the genus *Noelaerhabdus* (first occurrence in sample IM-28), which becomes increasingly common and forms nearly monospecific assemblages near the top of the studied sequence.

In contrast to the Sarmatian, Pannonian nannofossil assemblages are marked by significant shifts in diversity. They are composed largely or predominantly of endemic taxa and much less affected by redeposition. This reflects stable marine conditions throughout the Sarmatian and large-scale environmental fluctuations in the Pannonian.

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Using bivalves and foraminifers to infer Serravallian seawater temperatures in Vienna Basin shallow waters

Currently, there is significant research focus on interpreting paleoenvironments and understanding ecosystem resilience. Paleoenvironmental reconstruction entails considering various factors like salinity, trophic conditions, and freshwater influx. Among these factors, paleotemperature holds particular importance. Both present and ancient small marginal seas exhibit rapid responses to changes in climate-affecting factors, rendering them optimal for studying resulting alterations and their consequences. The bays of the Paratethys can be used for such small-scale studies yet it is necessary to carefully select appropriate fossil organisms and geochemical analyses employed.

For purposes of our research the following calcareous foraminifera: *Ammonia parkinsoniana*, *Ammonia inflata*, *Elphidium glabrum*, *Bulimina elongata*, *Heterolepa dutemplei* and aragonite bivalve shells of *Glycymeris deshayesi* were chosen. These organisms precipitate their tests and shells in equilibrium with the surrounding water by which chemical signals and different elements are bound and preserved (Peral et al., 2022). Stable isotopes analyses of ($\delta^{18}O$, $\delta^{13}C$) were used in our research. Through the ($\delta^{18}O$) isotopic values we calculated the approximate temperatures of surrounding sea which the shells and tests precipitated in.

Samples used in our study come from north-eastern (Slovak part) of Vienna Basin, part of Central Paratethys. Studied samples were collected from outcrops (Borský Mikuláš – vinohrádky/BM – early Serravallian, Devínska Nová Ves – clay pit/DNV – early Serravallian, Lakšárska Nová Ves/LNV – early Serravallian) and from the well (Holíč HC-4 – late Serravalian). Methods used in preparation for foraminiferal analyses were wet sieving and picking. Approximately 250 tests of foraminifera from each sample was picked for broad micropaleontological analyses, from which 10 to 30 individuals per species were used in geochemical analyses (126 analyses in total). The shells of G. deshayesi were embedded in epoxy resin and cut in half longitudinally. Altogether 123 samples were collected from the shells by use of New Wave Micromill in accordance with sclerochronological methods (Schöne a Surge, 2012). Geochemical analyses were performed on isotope ratio mass spectrometer (McCrea, 1950). Temperatures were calculated according to their specified age through the Serravallian. Different equations were used to calculate temperatures due to the aragonite composition of bivalve shells and calcareous tests of foraminifers. Equation used for bivalve was proposed by Dettmann et al. (1999). Equation used for foraminifers was proposed by Shackleton (1975). Results of geochemic analyses revealed the values of ($\delta^{18}O$) for each site. Site BM showed values of ($\delta^{18}O$) between -1,96 to 2,09‰ for bivalve shell and for foraminiferas values ranged between -1,18 to 2,19‰ ($\delta^{18}O$). Site DNV values ranged between -3,25 to 2,61‰ ($\delta^{18}O$). Site LNV values ranged between -4,22 to 1,81‰ ($\delta^{18}O$). Site HC-4 values ranged between -4,99 to -0,42‰ ($\delta^{18}O$). Final calculated temperatures in all sites ranged between 5 and 35°C. On the *G. deshayesi* shell from site BM seasonal temperature changes were observed throughout the bivalve lifespan. Temperature values during warm season averaged around 22°C, through the cold season average temperature was 15,.7°C. The results showed us that different studied sites sedimented in various environments, from deep cold waters with dysoxic sediments (DNV) through shallow waters with good oxygen input (BM, HC-4). At DNV and LNV sites the paleoenvironment changed through the sedimentation of the studied succession. Site HC-4 contained some redeposited foraminifera tests.

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Stratigraphic and paleoenvironmental insights into the Miocene deposits of the southeastern Pannonian Basin, Serbia

The Pannonian Basin System (PBS) experienced profound paleogeographic and paleoecological transformations during the Miocene epoch. Despite encompassing a relatively brief temporal span of approximately 15 million years, this period was marked by a series of transitions between continental, marine, brackish water, lacustrine, and once again continental environmental conditions. The primary objective of this research endeavour is to elucidate the evolution of Miocene sediments within the southeastern segment of the PBS, specifically encompassing the region of Serbia. This investigation relies on both well data and seismic data to confront the intricate challenge of characterizing the diverse depositional environments that coexisted within the same chronological interval.

The Early Miocene strata exhibit sparse fossil remains and are predominantly characterized by continental river and lacustrine sediments. These sedimentary deposits exhibit non-uniform distribution throughout the entirety of the Serbian sector within the Pannonian Basin, displaying heterogeneous thickness. Lower Miocene sediments manifest maximal continuity and thickness in the southern sector, encompassing the regions of southern Banat and the Drmno Depression, where their thickness reaches several hundred meters. Conversely, in the northern Banat region, these sediments are conspicuously absent. This distribution aligns with the hypothesis of asymmetric simple shearing contributing to the formation of the PBS (Matenco and Radivojević, 2012; BALAZS et al., 2021). In the subsequent Badenian, genuine marine conditions were established, with fossil assemblages from these sediments indicating both shallow and deep marine environments. The uplift of the Carpathian Mountains disrupted the area's connection to the sea (Ter Borgh et al., 2014) precipitating brackish water conditions that had a discernible impact on the fossil record. As the Miocene progressed, salinity levels decreased, giving rise to Caspian-brackish and freshwater conditions during the Pannonian stage (Magyar et al., 1999), and water depth variations can be discerned through the analysis of mollusk and ostracod fossils (Magyar and Geary, 2012). Mammal biostratigraphy, radiometric dating, magnetic polarity profiles together with biostratigraphy of microplankton and molluscs are the tools by which the Lake Pannon biostratigraphic system is connected to the global geochronological scale.

The delineation of these paleoenvironmental conditions carries substantial implications for a range of industries, including hydrocarbon extraction, coal mining, and geothermal energy (Radivojević, 2023). Most of the oil and gas production in the PBS is intricately linked to Miocene sediments, which serve as the principal source, reservoir, and seal rocks. Moreover, fossil remnants not only offer insights into climate fluctuations but also serve as valuable analogs for comprehending contemporary environmental dynamics.

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An integrative paleoenvironmental and chronostratigraphic study of the Neuhofen Formation (Lower Miocene, Germany, Central Paratethys)

Uncertainties in relation to chronostratigraphic correlations have limited our understanding of the possible impact of global-scale climate signals on the epicontinental sediments of the North Alpine Foreland Basin. In an effort to resolve the problem, we have carried out a detailed paleoenvironmental and chronostratigraphic study of an 18 m thick section of the marine, Ottnangian (middle Burdigalian) Neuhofen Formation at Mitterdorf, SE Germany (Fig. 1) (Hofmayer et al., 2023). Based on section logging, sampling of microfossils and nannoplankton, and analyses of stable oxygen and carbon isotopes, we demonstrate that significant environmental changes took place during the deposition of the Neuhofen Formation at Mitterdorf. In particular, the presence of nannoplankton zones NN3 and NN4 necessitated a re-interpretation of existing magnetostratigraphic data from Mitterdorf. To determine whether the observed environmental changes can be placed in a supra-regional and global context, a new chronostratigraphic framework was established for the study area using a multi-proxy approach based on 3-D modeling, litho-, bio-, and magnetostratigraphy, literature data and statistical analyses of new and previously published microfossil data. The results reveal that the Mitterdorf section can be correlated with polarity chrons C5Dr.2r and C5Dr.1n and that its age is 17.78–17.65 (vs. 17.65–17.50 Ma or 17.95–17.85 Ma in earlier works). Furthermore, the results show that the deposition of the entire Neuhofen Formation took place during the interval from 18.1 to 17.6 Ma, and that most of the accompanying environmental changes did not occur isochronously across its range. Nevertheless, comparison of literature-based global datasets with our new data indicates that the 3rd order sea level highstand at 17.85 Ma had an impact on the environment of the NH Fm. Furthermore, transition from eutrophic, open marine to mesotrophic, shallow marine conditions at Mitterdorf coincides with minima in orbital eccentricity and global carbon isotope values at 17.67 Ma. Our results are summarized in paleoenvironmental models of three time-points within the middle Burdigalian in the North Alpine Foreland Basin.

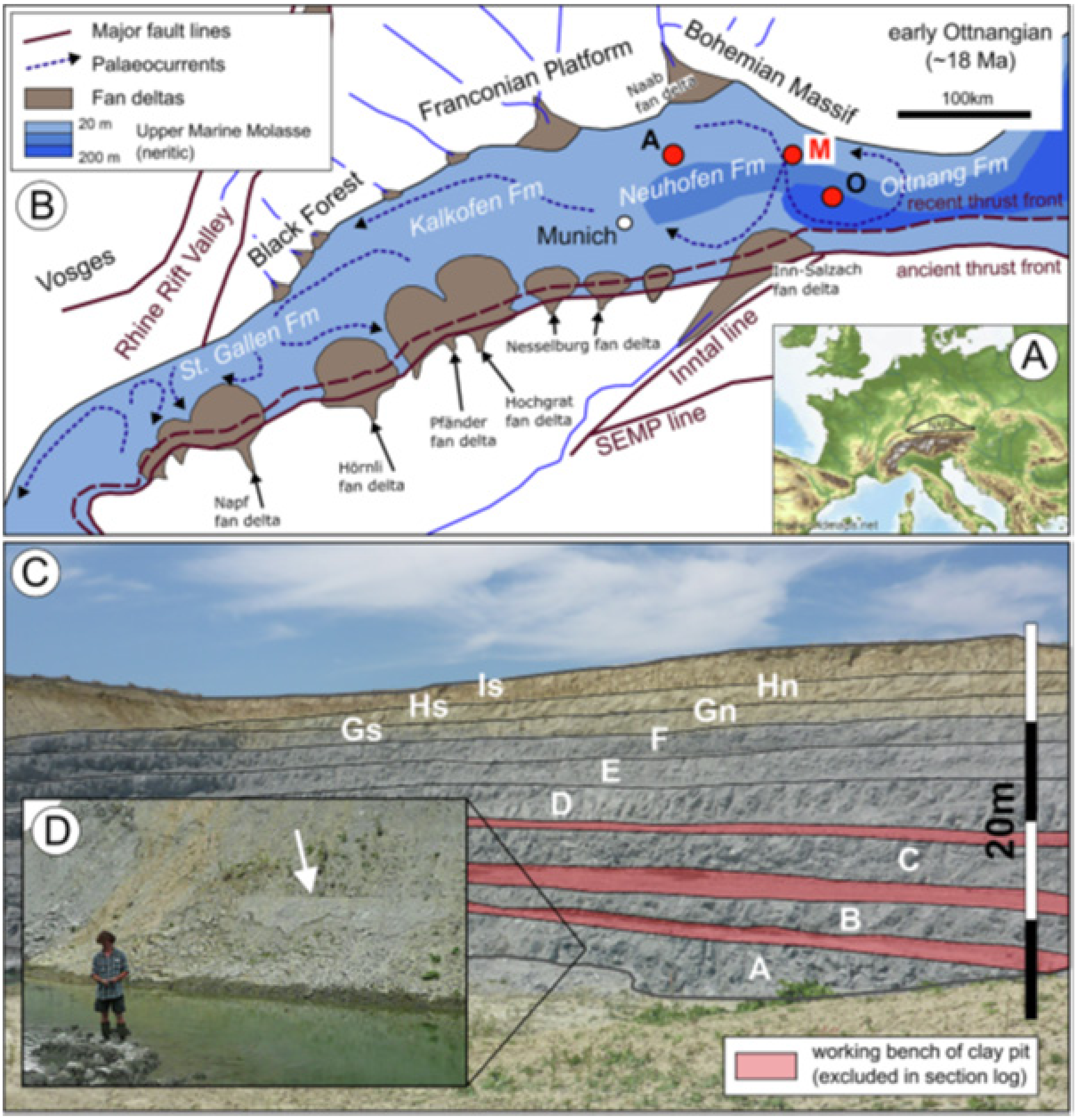

Figure: (A) Location of the North Alpine Foreland Basin (NAFB) in Central Europe. (B) Location of the study site Mitterdorf (M) and schematic depiction of the paleoenvironment of the NAFB during the Burdigalian (c. 18 Ma) (A, borehole Altdorf; O, outcrop Ottnang Schanze (C) Overview of the claypit Mitterdorf and the studied subsections A–I. (D) Close-up of subsection A showing a clear bedding plane (arrow) (Hofmayer et al., 2023).

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Genus Sphaerogypsina, Miocene type species from the Vienna Basin and its ancestors and descendants

When Reuss (1848) published a monograph on fossils from the Miocene sediments of the Vienna Basin (Nussdorf type locality), he described a small chessboard-like structure as *Ceriopora globulus*. Since then, numerous findings of these skeletal forms have been published. Untill 1998 (Pignatti, 1998) 128 papers have been registered. The holotype (No 16) of *Sphaerogypsina globulus*, renamed by Golloway in 1933, is in a collection of the Geological and Paleontological Department of the Natural History Museum, Vienna. The type locality coordinates are 48.262042 N, 16.349341 E. The marine Badenian comprises coralline algal limestone, common benthic foraminifera (Papp et al. 1970) and an ecostratigraphic zonation, now known as the middle and late Badenian transgressive cycle (Siedl et al. 2020, Jamrich et al. 2024). At the Badenian/Sarmatian transition the species becomes extinct in the Paratethys (Cicha et al. 1998).

The distribution of this genus extends in age from the Eocene – Pliocene until recent times and geographically from the Carribean Sea, across the Mediterranean to the Pannonian Basin and to Romania, Greece, Turkey, Armenia, Somalia to the Indo-Pacific region, including Japan (Matsumaru 1996, Hottinger et al. 1993).

In our studies we selected representative samples from the oldest to the most recent in the region of the Tethys and Paratethys (No 1-30). Of notable importance is the same magnification in all specimens for a clear interpretation of shells sizes (Figure). The oldest species (No 1–14) are larger than the youngest (No 20-30) but middle-sized shells also exist. A spherical shape is characteristic with an embryonic apparatus (marked in red) in the centre, which can adapt its relative position in hemi-spherical forms (No 17, 19, 20, 21, 26).

A special feature that is noticeable in this selection is the Eocene representatives that are all spherical with a precise position of the embryonic apparatus in the centre. In the middle, juvenile chambers of larger dimensions than younger ones, as well as smaller chamberlets in the adult and gerontological stage can be seen. The exceptionally low cycles of growth of the orbitoidal style form the basis for the new genus of *Orbitogypsina globulus* Matsumaru, 1996 (No 3, 4, 6 and probably also 7, 8). The classical internal structure of *Sphaerogypsina globulus* with a juvenile centre and transition to a cyclical stage of growth is shown in the sample from Ravna gora (No 14). Stacks touch each other in a zig-zag radial direction (No 14, 19). Evidence of growth of the chamberlets of the last cycle over the previous one is the uneven surface of the shell with a special chessboard-like pattern (No 3, 13, 22, 27, 28, 30) with large chamberlets and No 16, 23 with small ones (marked by circle). These differences could be sufficient to name a new species with necessary analysis of the internal structure (Drobne et al. 2014, 2017). For future research we need a large number of isolated shells, distributed along the depths in a recent marine environment (No 31) and the utilisation of modern 3D imaging, for example with Zeiss Micro XCT.400 (available at ZAG, Ljubljana).

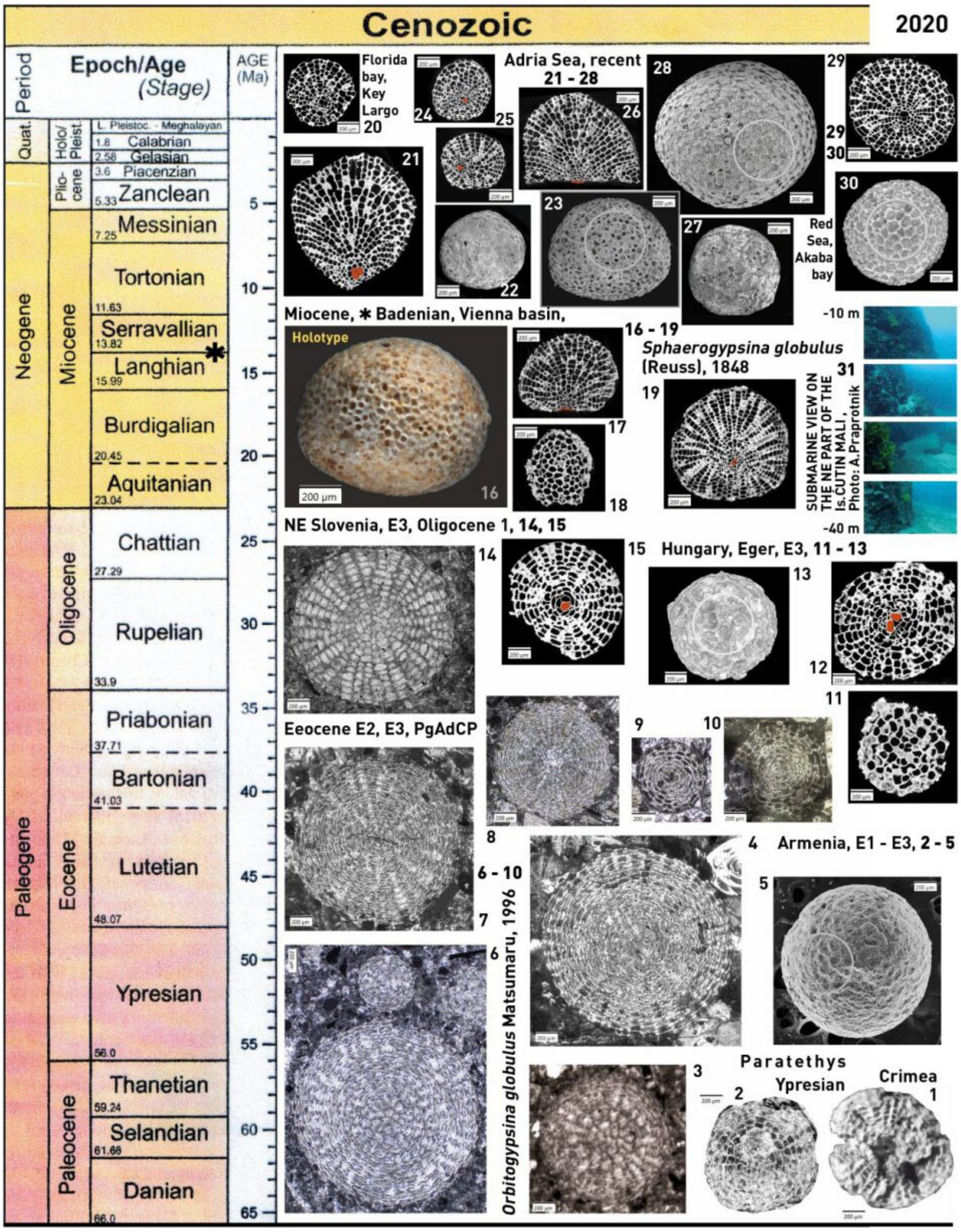

Figure:
Sphaerogypsina from the Vienna Basin and its ancestors and descendants.

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Paratethys sea temperature evaluation based on oxygen isotope composition of Badenian foraminifera; Nježić locality (North Croatian Basin, Croatia)

During the most part of the Badenian (Middle Miocene), the Paratethys sea covered the North Croatian Basin (NCB), situated in the SW part of the Pannonian Basin System. Badenian deposits crop out on the southwestern slopes of the Papuk Mt. (SE part of NCB, Slavonia Region). Within the 140 m long succession at the Nježić locality, four lithofacies can be distinguished: algal limestone, marl, bioclastic limestone and tuff. The age obtained by $40^{Ar}/^{39}Ar$ method on volcanic glass in the lower part of the succession is 14.40 ± 0.03 Ma. About 70 % of the sequence is composed of fossiliferous marls, rich in benthic and planktonic foraminifera and calcareous nannoplankton, whose presence suggests that the studied section belongs to the Lagenidae Zone, M5–M6 and NN5 Zone of the late early to middle Badenian (Marković et al., 2021). From 18 selected samples, specimens of planktonic foraminifera *Globigerina bulloides* and *Trilobatus trilobus*, and benthic *Lenticulina* sp., were selected to determine the stable isotope composition of carbon ($d^{13}C$) and oxygen ($d^{18}O$). The $\delta^{18}O$ value of ambient water in the Miocene is assumed to be 0 ‰ (Gonera et al., 2000). The δ^{18}Ocalcite (VPDB) signal of *T. trilobus* ranges between −6.24 and −1.06 ‰, and $d^{13}C$ from –0.62 to 1.53 ‰. For *G. bulloides* $\delta^{18}O$ ranges from −6.44 to −1.19 ‰ and δ13C from –1.47 to 1.23 ‰. The δ^{18}Ocalcite (VPDB) signal of *Lenticulina* sp. ranges from –0.12 to 0.60 ‰, and d13C from –0.03 to 0.79 ‰.

The $\delta^{18}O$ values of fossil foraminifera enables reconstructions of the sea temperatures and paleoclimate, even though ecological factors, as well as diagenetic processes – due to burial and recrystallisation can influence the initial values and result in lower $d^{18}O$ values. The suggested paleotemperatures are calculated according to Bemis et al. (1998) for *Globigerina bulloides*, Spero et al. (2003) for *Trilobatus trilobus* specimens, whereas the equation from Shackleton and Kennet (1975) was used for *Lenticulina* sp. to determine bottom water temperatures. The analysed planktonic foraminifera from the lower part of the succession suggest temperatures ranging from 18 to 25°C and thus point to warm, even tropical conditions and possible stratification of the water column. Similar paleotemperatures were calculated for the Slovakian part of the Vienna Basin (Kováčová et al., 2009) and Czech Republic (Scheiner et al., 2017). Temperatures higher than 25°C are not realistic and point to diageneticaly altered samples. The $\delta^{18}O$ values from benthic foraminifera suggest 15 to 16.9°C in the lower, 14.3°C in the middle and 17.4°C in the upper part of the succession, showing differences between the bottom and surface temperatures of ~4°C during the deposition of the lower part of the studied succession.

Lower $d^{13}C$ values of Globigerina specimens suggest increased productivity in surface water (Loubère, 1996), while common positive $d^{13}C$ values of *Trilobatus* probably result from symbiotic activity. The presence of symbionts might have caused lower carbon isotope ratios, enabling us to conclude that surface temperatures were probably lower than 25°C

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Integrated sedimentological, well log, seismic and palynological data of Upper Miocene sediments in the Northern Banat, Serbia

On the basis of regional Neogene column of Upper Miocene deposits in the southeastern part of the Pannonian Basin can be separated into three sedimentary and tectonic cycles (Horvath et al., 2015). The first cycle is represented by deep-water marlstones, claystones and sandstone turibidites of the regional Endrod and Szolnok formations. Above them, the second cycle sediments are deposited in a delta plain environment which is represented by clastic and marly deposits of the progradational series of the Algyo formation (Magyar et al., 2013). Finally, above this progradational series, there are sedimentary deposits of shallow water, transitional and terrestrial environments of the Ujfalu formation.

The primary goal of this research was to confirm the direction of progradations and isolate sedimentary bodies of Upper Miocene with different lithological characteristics. The main challenge during this process was the geological characterization of seismic data, which is usually in a time domain and has a vertical resolution significantly lower than well data. Detailed lithological analysis of the wells was done using the method of cluster (lithotype) analysis of well logs. Cluster analysis of well logs is based on the recognition of similarities or differences in the physical characteristics of drilled rocks, in order to group them into clusters or electro facies. Considering that the seismic data is also a reflection of certain changes in the physical characteristics of the rocks, the cluster analysis in combination with seismic facies maps, represents an excellent input parameter for the formation of the initial 3D lithofacies model. The goal of this analysis was to create seismic facies maps which will, combined with lithotype analysis results, fill the petroleum system model with data on lithologies and their spatial distribution. After calibration, the final lithology facies maps are obtained.

Multi-disciplinary research also included the palynological and sedimentological analysis of the Algyo and Ujfalu formations. Sedimentological research included analysis of the sedimentary bodies that were separated by using interpreted horizons and seismic attributes. The examined segment of the sedimentary series stratigraphically belongs to the Upper Miocene - Pliocene (second and third cycle deposits). Using two seismic attributes, "mean amplitude" and "RMS amplitude" it was possible to define some of the sedimentary bodies in this environment and confirm their characteristics based on the lithotype analysis results.

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How, when and where did the first „mid-Miocene“ marine transgression, happen in the Paratethys?; a case study from the North Croatian Basin

Until recently, it has generally been thought that the first mid-Miocene transgression started in the Central Paratethys in the mid-Badenian calcareous nannoplankton Zone NN5 (Martini, 1971), i.e., foraminiferal Subzone MMi5b (Lirer et al., 2019) that belongs to TB 2.4 sea-level cycle (Kovač et al., 2018). Now, the neglected previous data of studied sections Tisovac and Ivan Dol by Kopecká et al. (2022) amended with recent and past data from the North Croatia basin and broader has been incorporated to elucidate the beginning of the “mid-Miocene” transgression in the region. The usage of some bioevents in the Paratethys, such as foraminifera *Praeorbulina circularis* first occurrence (FO), should be abandoned because it falls within the gaps in the Mediteranean (Iaccarino et al. 2011), while the neglected Miller et al. (1991) globally astronomically calibrated FO of *Orbulina suturalis* (15.2 Ma) to the base of C5Bn in the North Atlantic is amended herein. For the first time, the first marine transgression, that belongs to TB2.3 sea-level cycle, has been connected with the opening of the known Slovenian marine corridor (Ivančić et al., 2018) at 16.057 Ma and now with the Arabian corridor, based on top common *Helicosphaera ampliamperta* and appearance of *Helicosphaeta mediterranea* respectively, where the latter only occurs in the Indian Ocean in NN4b Subzone (16.1 Ma) of Burdigalian (Okada, 1990). This is in accords with the intensified tectonic extension, and broader climate instability connected with the Mi2 event, during the late Karpatian. In addition, the Karpatian/Badenian boundary in Tisovac is set up based on the cold-water to temperate form shift of *C. pelagicus*, which is orbital in origin and in accord with cooler climate that prevails in the late Karpatian, while it is warmer in the Badenian. Marginal seas are more affected by change, which is the cause of regional bioevents. Because of an open gateway between the Mediterranean and Indian Ocean in the late Karpatian, they are, in this particular interval, closer to global bioevents that usually thought.

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Cidaroids (Echinoidea, Cidaroida): pioneers in benthic ecosystem engineering

Access and competition for hard substrate is a critical factor in the distribution and diversity of organisms, especially in deep-water benthic environments. In this context, we present a unique association of grypheid oysters *Neopycnodonte navicularis* Brocchi 1814 settling on the spines of echinoid *Stylocidaris polyacantha* (Reuss, 1860), from Middle Miocene (Badenian) mudstones of Šentilj in northeastern Slovenia. The sediments are interpreted as having been deposited in a rather calm environment of a muddy deep lagoon (> 30 m) behind a protecting coral reef.

Oysters are important ecosystem engineers, with a tendency to aggregate in large numbers creating bioconstructions that can reach significant lateral and vertical dimensions, from banks, up to reefs (Angeletti and Taviani, 2020). In present day Mediterranean, the main reef-builders are oysters from the family Ostreidae (Ostrea edulis Linnaeus, 1758), constructing reefs at intertidal and shallow (0 - 20 m) depths (Walles et al., 2015). Gryphaeidae are also known to produce bioconstructions, but in deeper water (30 - 300 m), and this was the case also in the past, since at least the Middle Miocene e.g. *Neopycnodonte navicularis* (Dominici et al., 2019). It is well documented, that grypheid oyster reefs serve as habitat refuge for many organisms like decapods, molluscs, polychaetes among invertebrates, and a wide variety of fishes among vertebrates.

However, as research (Angeletti and Taviani, 2020) shows, even oysters have a hard time settling on the deep-sea bottom, covered exclusively with soft sediments, consisting of mud derived from the decomposition of pelagic organisms. They need hard mineral substrate, in form of allochtonous rock fragments or, as demonstrated here, other biotic substrates, such as shells.

Ectosymbiosis is commonly observed in extant marine ecosystems, as well as documented in past ecosystems (Williams and McDermott, 2004). Among biotic substrates a clade of echinoids, the Cidaroida, appears to be especially suitable for ectosymbiosis. They can be locally abundant, and with their large primary spines and low capacity for locomotion provide suitable sites for attachment for sessile species. An important trait of the shaft of cidaroid spines, enabling the ectocommensals that attach to the primary spines of cidaroids and live among them is, that unlike in other echinoids, they are not covered by an epithelium and lack anti-fouling mechanisms (Märkel and Röser 1983), thus allowing unrestricted attachment.

Therefore, potential *Neopycnodonte* reefs, starting by settling on cidaroid echinoids, would represent a hotspot of biodiversity, surrounded by a soft sediment bottom. Research of benthic fauna of the Antarctic deep sea (Hétérier et al., 2008) confirms the importance of cidaroids as primary ecosystem engineers of benthic communities. Their analyses of species distribution suggests that the cidaroids are a favoured habitat for sessile organisms, compared to nearby rocks, but are colonized by relatively specialized sessile species, leaving the unfavourable rock habitat to more generalist species. This can be explained by the fact, that most of the epibionts are filter-feeding organisms that need to be in the water flow to survive. Unlike to the cidaroids, rocks can sink into and become covered with mud, while cidaroid spines offer a permanent position in the water column. Similar prevention from burial has been shown to be one of the major benefits of symbionts of hermit crabs (Williams & McDermott 2004).

To conclude, the unique association of grypheid oysters attached to the cidaroid spines suggests that the presence of cidaroids in the Middle Miocene of the Paratethys increased benthic biodiversity by providing attachment sites for ectosymbionts. It supports the hypothesis that cidaroids have been a key species of the benthic soft bottom ecosystems, facilitating the settlement of many others.

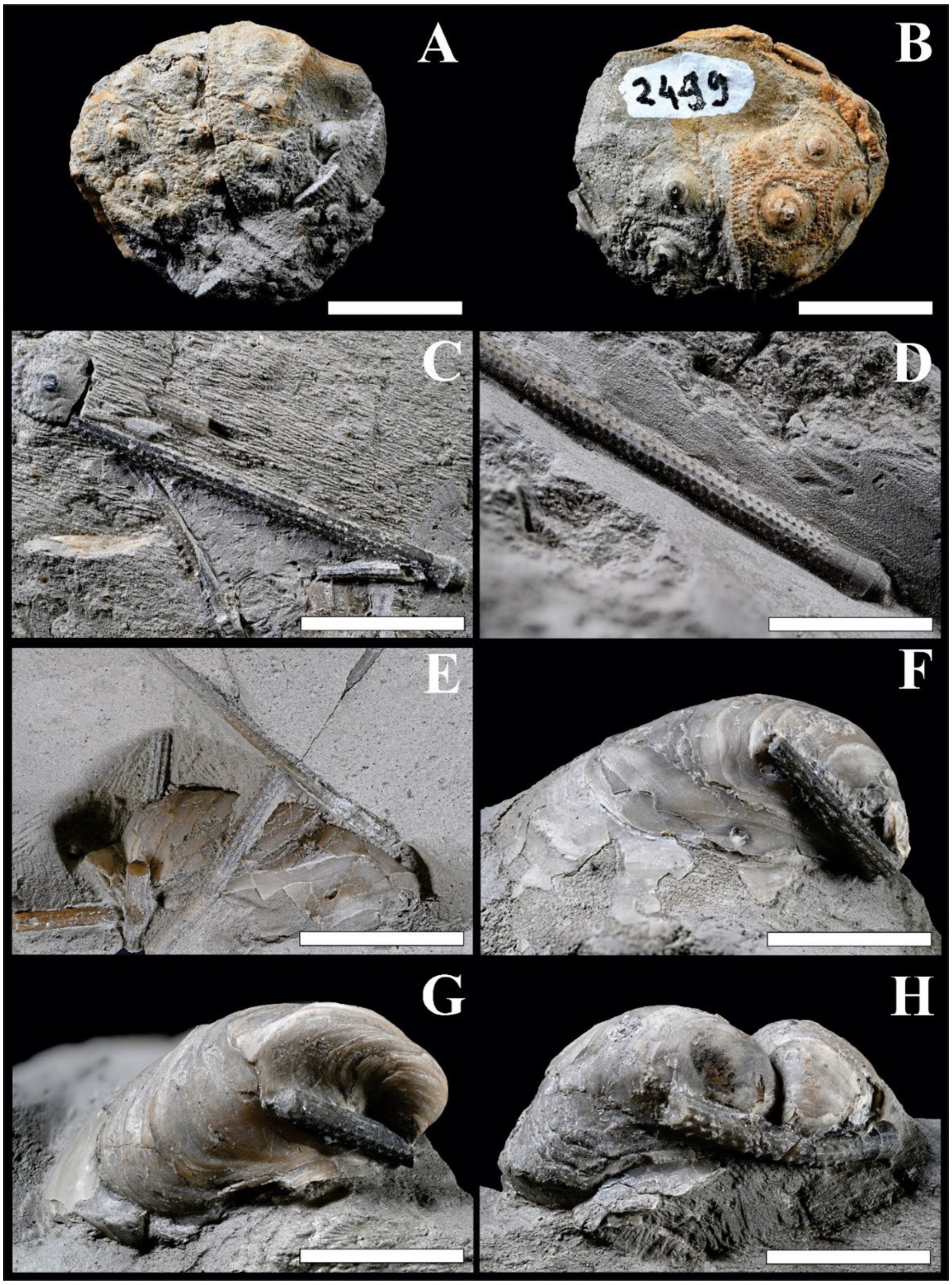

Figure:
A - *Stylocidaris polyacantha*, aboral view; B - *Stylocidaris polyacantha*, oral view; C - *Stylocidaris polyacantha*, primary spine; D - *Stylocidaris polyacantha*, primary spine; E–H - *Neopycnodonte navicularis* attached to primary spine of *Stylocidaris polyacantha*. Scale bars are 10 mm.

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Coral-dwelling barnacles (Cirripedia, Pyrgomatidae) from the Neogene of Slovenia

Coral-dwelling barnacles (Pyrgomatidae) are obligate symbionts of scleractinian corals. Their external calcified shell is located at the same level as the coral surface, and the coral tissue often grows over the barnacle.

The family Pyrgomatidae is divided into three subfamilies: Ceratoconchinae, Megatrematinae, and Pyrgomatinae (Chan et al. 2021). Extant Pyrgomatidae have a cosmopolitan distribution in tropical to temperate regions. Pyrgomatinae are Indo-Pacific, Megatrematinae and Ceratoconchitinae are distributed mostly in the Atlantic Ocean (Simon-Blecher et al. 2007).

The base of coral barnacles is cup-shaped and embedded in the skeleton of the host coral. The base bears concentric growth lines and longitudinal ribs which correspond to the internal ribs of the compartments. Some extant *Pyrgoma* have perforations in their bases that allow chemical and metabolic communication between the host coral and the barnacle (Ross and Newman 1973, Ross and Newman 2002, Chan et al. 2013, Yap et al. 2023). Most pyrgomatids have flat discoidal or elliptical-shaped shells. Barnacles that do not symbiotically inhabit corals commonly possess six compartmental plates, whereas pyrgomatids (*e.g. Ceratoconcha*) have four compartments: a rostrum (with two radii), two carino-latera (with one radius and an ala), and a carina (with two ala). Shells of *Pyrgomina* can even be fused into a single plate. The orifice, located in the central part of the shell, is where microscopic food particles are captured, it is opened and closed by a pair of opercular plates (scuta and terga). These opercular plates are either of the "balanoid type" as seen in *Ceratoconcha* or highly modified as in *Pyrgoma*.

The fossil record of the family dates back at least to the Early Miocene (Santos et al. 2012). Fossil ceratoconchids were common in the Paratethys, Mediterranean Sea, and Atlantic Ocean during the Neogene (Baluk and Radwanski 1967, Baarli et al. 2017, Gale et al. 2021). *Ceratoconcha* reached its greatest diversity in the Paratethys in the mid and early Late Miocene (Baarli et al. 2017) and its occurrence has been restricted to colonial hermatypic corals, *e.g. Tarbellastrea*.

In the Badenian, during the Middle Miocene Climate Optimum, tropical coral reefs extended into the Central Paratethys for the only time in the Neogene. These are low diversity coral reef ecosystems (usually less than 5 genera) with characteristicaly low framework-building capacity. Non-framework forming coral communities and coral carpets dominated while coral patch reefs formed just briefly and in geographically restricted areas sheltered from siliciclastic input (Riegl and Piller, 2000).

Herein we present for the first time new records of pyrgomatids from the Middle Miocene of northeastern Slovenia. The specimens were recovered from biostromal coral facies within lithothamnium limestones in localities Duplek, Šentilj and Ciringa. Some of the pyrgomatid specimens are preserved associated within host corals and some are isolated within the matrix. Regardless, six different species of scleractinian corals have been described from these localities: *Favia melitae* (Chevalier, 1961), *F. macdonaldi* Vaughan, 1919, *Solenastraea hyades* (Dana, 1846), *Tarbellastraea russoi* Bosellini, 1996, *T. aquitaniensis* Chevalier, 1961, and *Mussismilia vindoboniensis* Chevalier, 1961 (Baron-Szabo, 1997)

The investigated specimens of coral-dwelling barnacles include the Ceratoconchinae with four compartments: Ceratoconcha sp. 1 (RGA2481, RGA2485, RGA2489, RGA5907, RGA6848), Ceratoconcha? krambergeri (RGA2482) some of the latter possessing original coloration, Ceratoconcha? darwiniana (RGA2490), Ceratoconcha? sturi (RGA2486, RGA5907); and the Megatrematinae with a single fused shell: Pyrgomina? costata (RGA2379, RGA2381). Presented specimens, sometimes found associated with the coral Solenastrea? hyades, are referred to as Ceratoconcha and Pyrgomina with some caution, as opercular plates have not yet been recorded. These pyrgomatids represent the first known coral-inhabiting barnacles from Slovenia and fill in a gap in the geographical distribution of the family in the Paratethys during the Miocene.

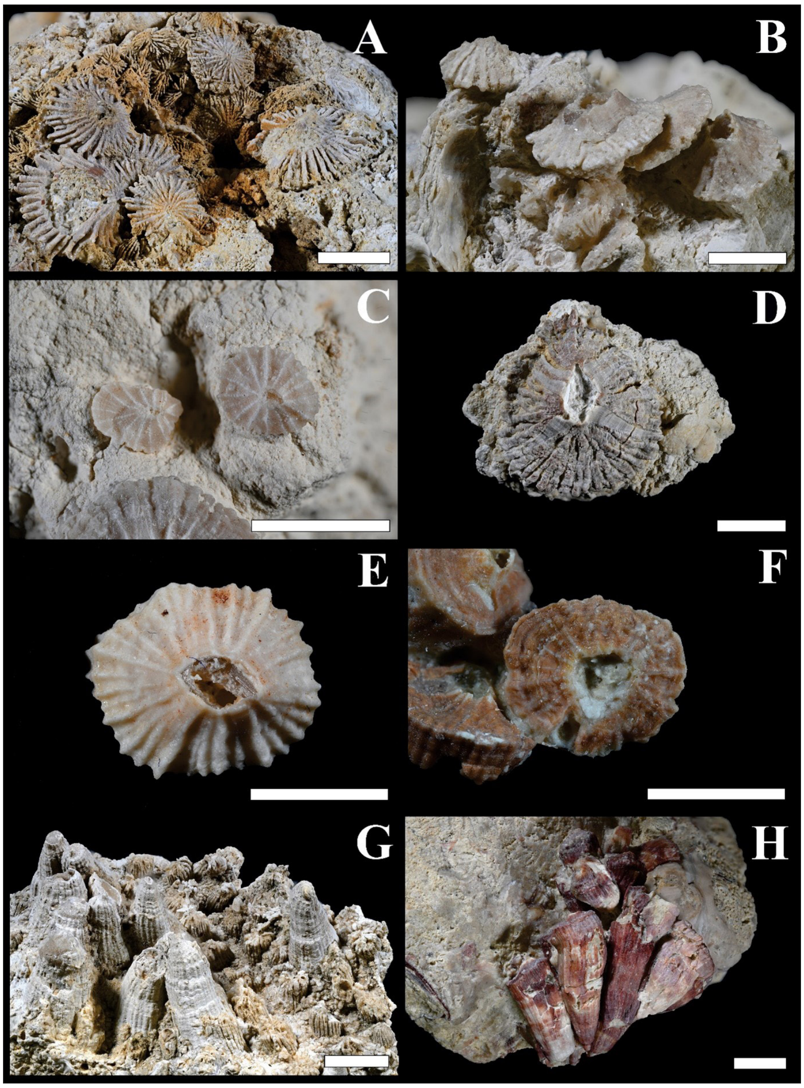

Figure: Pyrgomatidae from NE Slovenia: A - *Pyrgomina* cf. costata; B - *Ceratoconcha* sp.; C - *Ceratoconcha* cf. sturi?; D - *Ceratoconcha* sp.; E - *Ceratoconcha* sp.; F - *Ceratoconcha* sp.; G - *Ceratoconcha*? sturi; H – *Ceratoconcha cf. krambergeri*. Scale bars are 5 mm.

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The Lower Miocene succession of the southern Waschberg Unit in Lower Austria

The Waschberg–Ždánice Unit links the Alpine and Carpathian orogens. Its complex structural and sedimentary structures lack a modern interpretation, particularly in the Austrian part. In recent years, the southern end of the Waschberg–Ždánice Unit (i.e., the Waschberg Unit) has been geologically mapped in detail. In this contribution, we present the occurring formations, their fossil and sedimentological inventory and peculiarities, and the structural deductions. The Waschberg Unit comprises the Michelstätten Formation (marlstone, late Egerian to early Eggenburgian, NP25 to NN2, N4b to N5) and the Ždánice-Hustopeče Formation (marlstone, sandstone, claystone, Egerian to Eggenburgian, upper NN2 to NN3, N5 to N6) which forms the vast majority of the rocks. Enveloped in the Ždánice-Hustopeče Formation are boulder beds and several olistoliths of various age, composition and size. These include the "Blocky Layers" with various crystalline components, Flysch-boulders, sands and marls with boulders up to 5 meters in diameter. These sediments are interpreted as debrites and are often associated with turbidites. Other large olistoliths comprises Lutetian and Priabonian marlstones and limestones. Most prominent are km-sized giant-olistoliths of Ypresian to basal Lutetian "Waschberg-Limestone" that glided into the depositional basin. In front of a thrust fault, Ottnangian limonitic clays and sands where thrusted and folded (Křepice Formation). The marine Karpatian Laa Formation was deposited in the Alpine-Carpathian Foredeep and became overthursted by the Waschberg–Ždánice Unit. Based on foraminiferal and nannoplankton data as well as sedimentological descriptions and structures, we reconstruct the depositional environments and describe the processes that formed this part of the Alpine-Carpathian orogeny. The mapping activity resulted in modern geological map sheets that were recently published.

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New data on Miocene crocodylians from the Fore-Carpathian Basin and its foreland

In Central Europe, the Middle Miocene Climatic Optimum was surprisingly distinct, partially due to favourable paleogeographic conditions – the connection with the Indo-Pacific bioprovince enabled circulation of marine waters that bolstered a subtropical climate, evidenced by both rich marine faunal assemblages of Indo-Pacific affinities and thermophilic terrestrial faunas.

During this timespan, two crocodylian genera inhabitated Central Europe: *Gavialosuchus* (often referred to as *Tomistoma*) – a marine long-snouted tomistomine with a body length of ca. 5 m, and *Diplocynodon* – a basal endemic alligatoroid, predominantly freshwater, with a body length of ca. 1.5 m.

Crocodylian remains from the Miocene of the Central Paratethys have been usually referred to as *Diplocynodon*, *Gavialosuchus* or left undetermined. They have been recorded in the Korneuburg and Vienna Basins, Zsámbék Basin, Styrian and Fohnsdorf Basins, and Pannonian Basin. They are also known from adjoining land areas in Bosnia-Herzegovina (Böhme and Ilg 2003).

In the southwestern Fore-Carpathian Basin (FCB), crocodylians were reported from the Ottnangian of South Moravia in Czechia (Rzehak 1912) and from Lower Austria (the holotype skull of *Gavialosuchus eggenburgensis*). The crocodylians in the Polish part of FCB are extremely scarce – one tooth is known from the Lower Badenian of Pińczów. Occurrences in adjoining land areas are limited exclusively to the Burdigalian of Most Basin (NW Czechia), where *Diplocynodon ratelli* was reported (Chroust et al. 2021).

The present report reappraises some previous crocodylian fossil record from FCB and describes a new important occurrence. The morphological features of this material point towards its ascription to the genus *Diplocynodon*.

1. A tooth from the Lower Badenian of Židlochovice (Czechia) from Anton Rzehak's personal collection, housed at the Paleontological collection of the Department of Geological Sciences, Faculty of Science, Masaryk University, Brno (ÚGV E1093). The specimen was correctly catalogued by Rzehak as a crocodylian tooth, but it was never formally reported in any of his numerous works.
2. A tooth from the Lower Badenian of Pińczów (Poland) collected by Andrzej Radwański, housed at the Museum of the Faculty of Geology, University of Warsaw (MWGUW/ZI/113/067). This tooth was previously attributed to *Tomistoma* (Antunes in Młynarski 1984); here reassigned to *Diplocynodon*.
3. A dorsal osteoderm from the upper Karpatian-?Lower Badenian freshwater deposits of the Szczerców mining field (Poland) that was collected by our prospecting team (M.G., R.K, S.L.-T.) in June 2023 during reconnaissance fieldwork in the Bełchatów lignite mine. The specimen is housed at the Museum of the Faculty of Geology, University of Warsaw (MWGUW/ZI/113/064). The latitude of the finding spot (51°14'00.0"N) makes this specimen the world's northernmost occurrence of a crocodylian in the last 23 Myr (i.e., from the Neogene to the present).

Figure:
A – A generalized paleogeography of the Paratethys in late Early Miocene-early Middle Miocene time with northernmost European occurrences of crocodylians within the Thanetian to Langhian timespan.

B – Recorded crocodylian-bearing sites in Miocene of Central Paratethys (black circles) with location of the discussed findings (asterisks). After: Rzehak 1912; Rögl and Steininger 1983; Młynarski 1984; Böhme and Ilg 2003; Kováčová et al. 2011.

The reappraised Fore-Carpathian material puts into question the assumed exclusively freshwater lifestyle of this Diplocynodon. Although the redeposition of resistant crocodile teeth into littoral environment by floods or erosion is very plausible, a marine lifestyle (at least partial) cannot be excluded.

Between the Thanetian and the Langhian (i.e., for over 40 Myr), the northern limit of crocodylian distribution in Europe was situated at approx. present-day 51°N parallel. However, the paleolatitude of the northern limit of the crocodylian distribution has been slowly increasing from ca. 42°N in the Thanetian to ca. 47°N in the late Burdigalian/Langhian.

In conclusion, a reappraisal of the crocodylian material of FCB shows that all known records in this area belong to the genus Diplocynodon, suggesting that this freshwater taxon may have ventured into marine environments as well. Finally, the crocodile osteoderm from Szczerców expands the known distribution of Neogene crocodylians towards more northern latitudes.

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Zircon U-Pb geochronology of Sarmatian bentonite from Hrvatsko Zagorje Basin (Croatia)

A layer of bentonite up to 40 cm thick on the Sutla-II lithostratigraphic section was deposited between horizontally laminated marls in the area of the northwestern part of Hrvatski Zagorje Basin (i.e. southwestern marginal zone of the Pannonian Basin System). Based on the biostratigraphic records (i.e. foraminifera, ostracods, calcareous nannofossils, palynology), it was concluded that the marls belong to the lower Sarmatian (Grizelj et al., 2023). The main component of the bentonite is montmorillonite, while opal-CT, calcite and quartz occur in small amounts. Zircon, apatite and ilmenite appear as accessory minerals. Based on the chemical analysis of the bulk sample of bentonite, it was determined that it was formed by intensive weathering of a felsic to medium-type volcanic ash (Grizelj et al., 2023). In addition, U-Pb zircon dating was performed using the LA-ICP-MS method. Zircon U-Pb dating indicates the age of the youngest age population: 12.38+/-0.2 Ma (MSWD 1.5). This confirmed the biostratigraphic age of bentonite. The described occurrences of bentonite are associated with a distant volcanic eruption. Which eruption is the source of the deposited volcanic ash (altered bentonite) is the subject of further research.

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Early Miocene large land mammals from the Drtija sand pit near Moravče

During the Burdigalian stage (late Ottnangian) of the Miocene, sea-level fall accentuated the beginning of isolation of the Paratethys from the Mediterranean Sea (Harzhauser et al., 2007). Except for the Northern Alpine Foreland Basin and its continuation into the Polish foredeep, no real marine environments are known from the Carpathian–Pannonian–Dinaride domain, and brackish to fresh water sedimentary environments prevailed (Harzhauser et al., 2007). During the Middle to Late Burdigalian (Ottnangian/Karpatian), large deltas were present along the young Alps. Formations derived from a fluviodeltaic system of flooding rivers and alluvial fans can be found in several places in Central Slovenia; i.e. Besnica, Tunjice Hills, and Moravče.

A rich assemblage of Early Miocene fossils was collected from an abandoned sand pit Drtija in the vicinity of Moravče, where quartz sandstone, conglomerate or gravel were extracted. Marine and lacustrine fauna is represented by bony fish (*Pagrus cinctus*), sharks (*Cosmopolitodus hastalis* and *Carcharias* sp.), eagle ray teeth (*Aetobatis arcuatus* and *Myliobatis* sp.) and turtles belonging to *Trionyx triungui*s. Frequent finds are oncoids which often formed around a central nucleus, in most cases freshwater gastropods Brotia (*Tinnyea*) eschery. The remains of nearshore environments are mainly represented by numerous occurrences of thick-shelled oysters *Crassostrea gryphoides* that formed Crassostrea-bioherms. Terrestrial ecosystems are defined by numerous fragments of fossil wood indicating the existence of mangrove habitats along the seashore.

The most important finds in the Drtija sand pit are the remains of Miocene land mammals. Isolated bone fragments of large mammals, broken and fragmented during the transport a can be found. However, most important finds are mammal teeth, which preserved much better in this high-energy environment. Almost all teeth are missing roots, and the enamel is polished, due to the water transport with the quartz gravel.

Most of the collected teeth belong to small tragulid ruminants of the genus *Dorcatherium*. Four teeth were discovered; a complete crown of the left lower M2 or M3, two unworn partial tooth crowns with mesial half of the right lower molar, and a distal cusp of the lower right M3.

Two teeth belong to even-toed ungulates of the genus *Hyotherium*; a complete crown of right M1 and a mesial pillar of lower left M3.

Additionally, remains of large mammals were also discovered. Two teeth specimens of rhinocerotid were collected from the sand pit; a polished part of the buccal lamella of the lower premolar/molar, and an almost complete very worn right P4 which we assigned to the genus *Brachypotherium*.

Mikuž and Pohar (2001) described an anterior part of left lower jaw with missing teeth belonging to elephant-like proboscidean of the genus *Prodeinotherium*. Later, a fragment of the lower molar of *Prodeinotherium* and also a completely preserved slightly worn crown of the right upper P3 was found.

The presence of large mammals is important for estimating the age of these beds. Until the Early Miocene, the open Tethyan Seaway to a large extent hindered land mammal migration between Africa and Eurasia (Harhauser et al., 2007). The collision of the Afro-Arabian plates with Eurasia during the mid-Burdigalian caused the emergence of a terrestrial corridor called the *"Gomphotherium Landbridge"*, which allowed a faunal exchange between Africa and Eurasia (Rögl, 1999). This and a warmer less seasonal climate enabled proboscideans from Africa to disperse towards Western Europe in multiple migration events. The first arrivals in Europe were gomphotheres 17.3 Ma before present followed by deinotheres (*Prodeinotherium*) 16.5 Ma before present (Van der Made 1996).

Based on the data above, the beds containing large mammals in Drtija sand pit were deposited in the Middle to Late Burdigalian, which corresponds to the period from Ottnangian to Karpatian in the Central Paratethys.

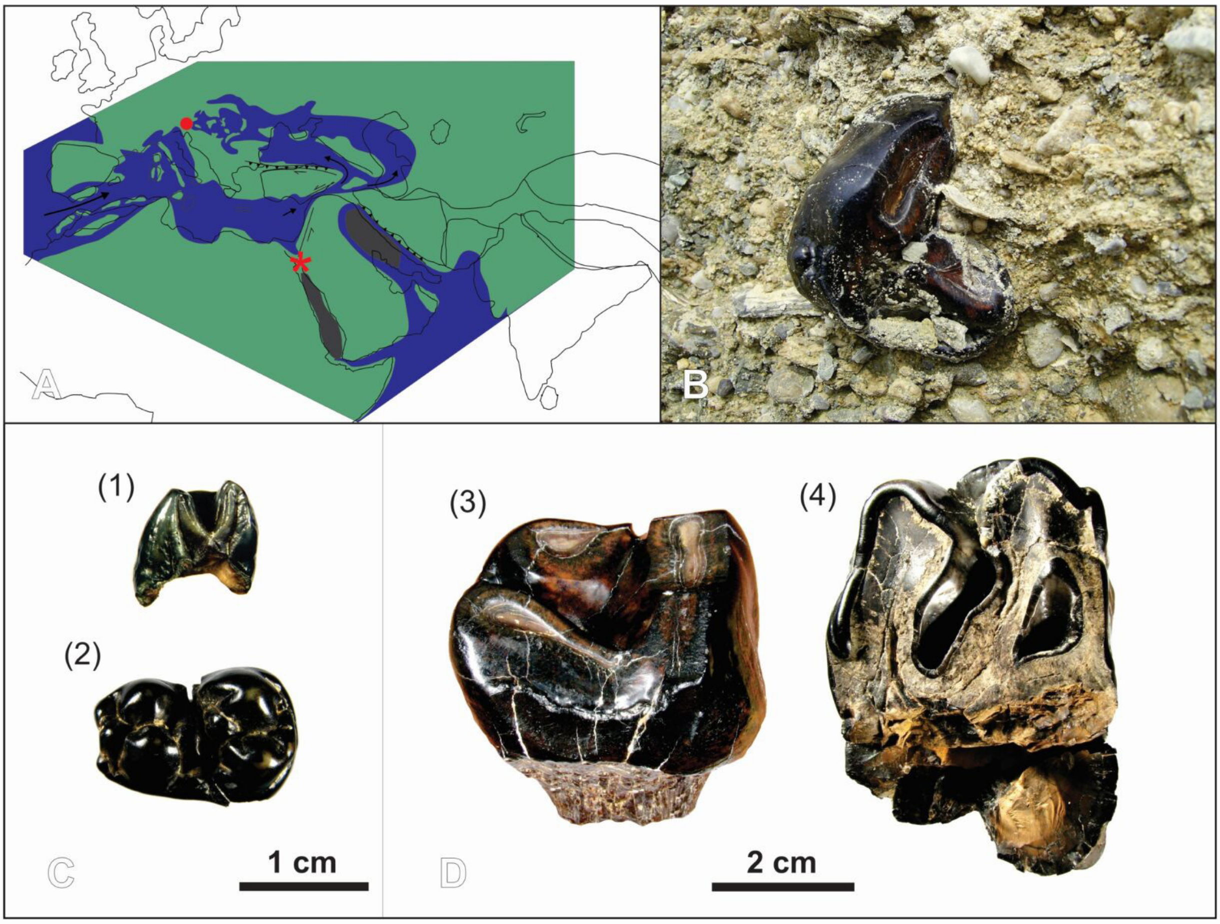

Figure:
(A) Paleogeographic reconstruction of the Mediterranean and Central Paratethys in the Lower Miocene. Simplified after Rögl, 1999. The location of Drtija is marked with the red dot and "Gomphotherium Landbridge" with an asterix. (B) Prodeinotherium tooth in situ. (C) Teeth belonging to (1) Dorcatherium and (2) Hyotherium; and (D) (3) Prodeinotherium and (4) Brachypotherium.

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The Upper Badenian seagrass meadows from the NE part of the Vienna Basins – multiproxy evidence

Seagrass/seaweed meadows represent "islands" of life in the marine "deserts" formed of muddy, sandy, stony or rocky substrates. The primary precondition for the evaluating the contribution of fossil seagrass/seaweed meadows to the shelf biodiversity is their successful identification in the rocks. The direct signal represented by seaweed/seagrass body fossils is rare. Other possibilities are indirect evidence based on the presence of protists and animals associated with seagrass/seaweed meadows or organic geochemistry and a biomarker study. Although some studies focused on the biogeochemistry of modern seagrass meadows (e.g. Ficken et al. 2000), they have never been tested for the application on fossil ecosystems, except in the Pleistocene (Ortiz at al. 2021).

We selected four localities with indicative seagrass foraminifera from the foothills of the Malé Karpaty Mts (Slovakia). All samples were studied by an integrated approach including paleontology (foraminifera, calcareous nannoplankton, molluscs, palynology), organic-geochemistry (n-alkanes, Pr/Ph-ratio) and elemental analysis.

Sections with index calcareous nannoplankton species (DNV BAZ, Fuch´s Quarry) can be correlated with NN6 zone. Palynomorphs are nearly absent, which is probably consequence of their oxygenation.

The Sandberg locality (SAN) is situated at the western slopes of Devínska Kobyla Hill. All samples are dominated by keeled elphidia (mainly *E. crispum*), which has been reported to dominate on *Ectocarpus* thalli (Langer 1988). The assemblages also include leaves microhabitat dwellers *Neoconorbina*, *Biasterigerina*, *Lobatula* and rare agglutinated foraminifers (*Textularia*). In algal limestones, the abundant epiphytic taxa as **Lobatula**, *Planorbulina*, *Elphidium*, *Miniacina*, *Biasterigerinata*, *Borelis* melo, and rare small miliolids were recorded. From algal species at SAN and STU localities the most abundant genus is *Mesophyllum*. Less frequent are *Lithothamnion*, *Lithophyllum* and *Spongites*, while *Titanoderma* and *Hydrolithon* are rare.

The locality Dúbravka-Fuchs´ Quarry (FQ) is situated on the eastern slope of Devínska Kobyla. Corallinacean clay beds and limestones contain epiphytic elphidia and *Asterigerinata*. Assemblages from overlying sandstones and conglomerates dominate by small miliolides, mostly *Pseudotriloculina rotunda* and elphidia. Special is the great abundance of pioneer arborescent settler *Miniacina miniacea*.

DNV BAZ Locality is situated on the Morava river bank in the Devínska Nová Ves vicinity. Samples contain Bryozoa, red algae, crab claws, fragment of molluscs, echinoderms, Cirripedia and fish bones. Foraminifera assemblage dominated by *Amphistegina*, epiphytic forms living at leaves microhabitat as *Lobatula lobatula*, *Biasterigerin*a, *Miniacina* and *Elphidium* sp. div., and rhizome microhabitat forms as *Rosalina*/*Discorbis* and *Textularia pala*. Infaunal forms (*Bulimina*, *Bolivina*, *Globocassidulina*) were rare. Plankton includes *Globigerina bulloides*, *G. regularis* and *Dentoglobigerina altispira*.

Locality Stupava - Vrchná Hora (STU) is located at the north-eastern border of the Vienna Basin. Foraminiferal tests are recrystallized and represents epiphytic forms as *Ammonia, Biasterigerina*, *Elphidium*. In algal limestone foramifers of D morphotype, typical

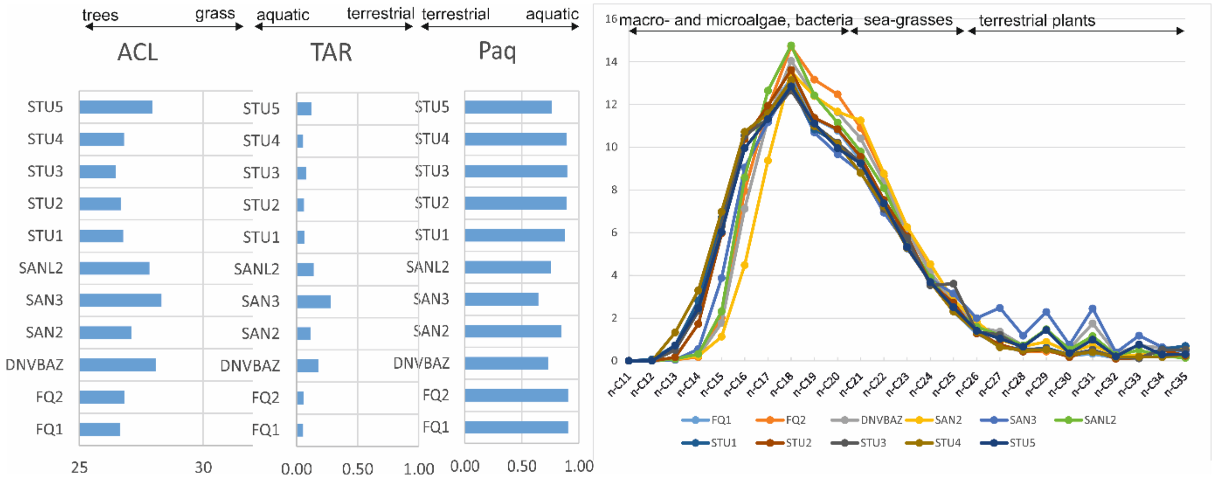

Figure:
Organic-geochemistry proxies measured in the study samples

for *Udotea* sp. algae (Langer, 1988) as *Quinqueloculina*, *Triloculina* are common.

Though studied localities differ by lithologies and paleontological content, the organic-geochemistry record is uniform (Figure). The clear evidence of submerged/floating macrophytes (= sea grasses) is represented by presence of C_{21}, C_{23} and C_{25} n-alkanes. The most abundant n-alkanes C_{16} – C_{19} indicate that the organic matter originates from algae (both micro- and macroalgae) and bacteria. Macroalgae can also be expected from body fossils of Corallinales found in all localities. The markers of terrestrial plants (n-alkanes > C27 and indexes TAR, Paq; Figure) indicate strong dominance of marine organic matter over terrestrial.

Pr/Ph (pristan/phytan)-ratio reached values between 0.59 and 0.70 suggesting anaerobic conditions.

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Decades of constant tweaks - microbiostratigraphic chaos of Vienna Basin (DCTMCVB)

Observations of microfossils in Miocene sediments date back to the late 19th century. Scientists such as Christian Gottfried Ehrenberg and Ernst Heinrich Haeckel made in 19th century pioneering contributions, laying the foundation for Miocene microbiostratigraphy. Since the mid-20th century, microfossil zones have played a key role, so paleontologists have identified and widely used them based on e.g. foraminifera, nannofossils, diatoms, radiolarians, dinoflagellates within the Miocene sediments.

Bramlette and Riedel (1954) first pointed out the stratigraphical significance of coccoliths, and the knowledge of Cenozoic nannoplankton increased rapidly since then. Zonations were defined by Brönnimann and Stradner (1960), Hay et al. (1967), Bramlette and Wilcoxon (1967), Roth (1970), Roth et al. (1971), Martini and Worsley (1970), Martini (1970), Bukry (1973) and Okada and Bukry (1980). Up-to-now widely accepted work in this field is zonation brought by Martini (1971). At the beginning of the Deep-Sea Drilling Project (DSDP), nannoplankton zonations were far behind their planktonic foraminifera counterparts. Besides the DSDP data, Martini also considered the shallow water sediments of continental Europe and N/S America. As a significant geological area, researchers have studied the Vienna Basin (VB) foraminifera and nannoplankton extensively for decades. Nannofossils from VB were studied by e.g. Herbert Stradner, Carla Müller, Ružena Lehotayová, and Aida Andrejeva Grigorovič using Martini`s (1971) zonation. Andrejeva Grigorovič et al. (2001) applied subzonation sensu Fornaciari et al. (1996) and Marunteanu (1999).

Regional biostratigraphic schemes based on foraminifera developed in parallel with taxonomic and stratigraphic research, beginning in the 1940s in the oil-producing parts of the USA (e.g. Cushman and Stainforth 1945) and Central Europe (Grill, 1941 – 48, Papp and Turnovski 1953). By the mid-20th century, such schemes reached high levels of sophistication in Western Europe (e.g. Bolli 1957a, b) and the former Soviet Union (e.g. Subbotina 1953). Generalizing these essentially local schemes was underway in the 1960s (e.g. Bandy 1964, Banner and Blow 1965), boosted by DSDP. This unification process in the Central Paratethys launched RCMNS commission by defining regional biozones and their correlation with global zones (Cicha et al. 1975). A specific approach has been used by oil companies where regional correlation horizons and local biozones are still in use (Irena Zapletalová, Věra Molčíková, Pavel Hudec). The recognition of biostratigraphic horizons (biohorizons) correlated between stratigraphic sections was broadly discussed in McGowran (2005). Following this work, Wade et al. (2011) revised and unified Cenozoic planktonic foraminiferal magnetobiochronology, which is the basis for the current trend. This was the basis for the work of Kováč et al. (2018) on the Central Paratethys regional scale.

Despite new knowledge, different biostratigraphic scales are still used. They do not always sufficiently clarify the relationships with other regions. On the other hand, changes achieved by obtaining and refining geochronological data sometimes leads to uncritical shifting of traditional local biozones in relation to time. However, the original biozones were not calibrated, and new data are often unavailable.

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Preservation of burrowing shrimps (Malacostraca: Decapoda: Axiidea) in Miocene siliciclastics of the Central Paratethys

Burrowing shrimps (Malacostraca: Decapoda: Axiidea) are soft-bodied, fossorial decapods inhabiting predominantly shallow intertidal and subtidal marine environments. Often living in high densities, they represent major bioturbators of muddy and sandy substrates having great impact on physicochemical properties of the sediment (Dworschak et al. 2012, and references therein).

Much of the burrowing shrimp's integument is reduced because the burrow walls replace many of the cuticle's functions. Due to the delicate nature of most of the cuticle, only the hardened parts are usually preserved, with heavily calcified chelipeds preserved most frequently, although other parts are sometimes preserved as well. Three main types of preservation in terms of completeness of the material can be observed for burrowing shrimps (Bishop & Williams 2005; Hyžný & Klompmaker 2015): (1) (Near) complete body fossil, in which the majority of all three main parts of the shrimp are present (i.e., carapace, legs, and pleon); (2) Disassociation unit representing a natural aggregation of exoskeleton elements commonly preserved together (i.e., cheliped disassociation unit, pleonal disassociation unit, etc.); (3) Isolated element of the exoskeleton found without any associated parts from the same specimen.

The sediments in which fossil burrowing shrimps lived were quite variable (as are those of their modern counterparts), but usually siliciclastic (sandy to muddy; with or without volcanoclastic admixture) to carbonate mud (Dworschak et al. 2012). In Miocene siliciclastic sediments of the former Central Paratethys, all three main types of preservation (as outlined above) can be documented at various localities. However, in Early and Middle Miocene clays of selected exposures yet another type of preservation was identified. In this type of preservation, the disassociation unit is preserved as a set of isolated elements preserved apart from each other but simultaneously close enough to be identified as originating from the same individual. This intermediate type of preservation (in respect to the categorization outlined above) required only minor post-mortem transport and virtually no physical disintegration following the final deposition. Such conditions were only rarely met in the known fossil record of burrowing shrimps.

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A review of the Neogene sedimentary successions in Eastern Slovenia

The Neogene sedimentary successions in north-eastern and eastern Slovenia reveal a complex interplay of tectonic activity, sea-level changes and climatic variations. Four major tectonic units come into contact in this region: Eastern Alps, Southern Alps, Dinarides and the Pannonian Basin System (PBS). Tectonic activity caused the formation of several faults and folds, which divided the area and influenced the sedimentation. The most prominent of them are the Periadriatic Fault (PAF), the Labot Fault and the Donat Fault (which continues as the Balaton Fault) and the Sava Folds. They led to distinct sedimentation patterns of three depositional units, each characterised by unique geological processes and depositional environments: north of the PAF, south of the PAF and south of the Sava Folds (Ivančič et al, in review).

North of the PAF, sedimentation was associated with the Mura-Zala and Styrian Basins. Neogene sedimentation started in the Karpatian and continued to Plio-Quaternary. Sedimentary sequences are united in various formations. The oldest is the Haloze Formation, represents a series of sedimentary layers from the Karpatian to the early Badenian. It is characterised by over 1300 metres of coarse to fine-grained sediments, deposited during the first syn-rift phase of the PBS in terrestrial, transitional and shallow marine environment. Succession is represented by conglomerates, sandstones, and muddy breccia, sandstones, marlstons and limestone (Maros et al., 2012). The Špilje Formation consists of sediments deposited from the early Badenian to the early Pannonian, deposited during the syn- and post-rift phases of the PBS. This formation is characterised by diverse sedimentary environment, ranging from shallow to deep marine settings, which facilitated the deposition of sandy turbidites. The Špilje Formation is significant for its considerable thickness, up to 1600 meters, and its role in documenting the transition from marine to deltaic environments. The Lendava Formation contains sediments representing the development of a large deltaic system, characterised by prograding delta and shelf-slope deposits and is notable for its fine-grained sediments and sandy turbidites. The Ptuj-Grad Formation compasses clastic sediments from the Upper Pannonian to the Pontian stage, illustrating a period dominated by braided and meandering river systems. This formation is significant for its detailed sedimentary record including gravelly sands and interbedded silty layers, which provide insights into the fluvial dynamics at the time, locally, alkali basaltic volcaniclastic deposits occur (Maros et al., 2012).

Neogene sedimentation south of the PAF continued from Oligocene. The oldest formation is called Govce formation, which include Egerian to Eggenburgian poorly lithified sediments (clay, sand, sandstone, marlstone, claystone, conglomerates) deposited in shallow marine, brackish and terrestrial environments. The Badenian sediments of the Laško formation discordantly overlapped the Govce formation. They consist of a mixture of marl and lithothamnium limestone, deposited in shallow marine environments. This formation is particularly noted for its rich bivalve and gastropod macrofossils, which provide valuable paleoenvironmental data and highlight its importance in the biostratigraphic correlation within the Central Paratethys. The Sarmatian Beds consist of sandy and clayey marl, calcarenite, and quartz sandstone. Deposited in a brackish environment, marked by a significant reduction in salinity and changes in the depositional environment, reflecting the final stages of marine influence in the region. In places the Sarmatian samples are known as the Dol formation (Pavšič and Horvat, 2009).

South of the Sava Folds, the Krško area represents the third depositional unit. Sedimentation took place in the Ottnangian and from the upper Badenian onwards. There are a number of Neogene formations, ranging from the Govce Formation, with coarse-grained terrestrial sediments, the Laško formation, which show similarities with successions south of PAF, the Drnovo Formation, which consists of Pannonian marls and represents a transition from a marine to a lacustrine environment. The youngest sediments include Bizeljsko and Raka formations, which represent later stages of deltaic and terrestrial sedimentation during the Upper Pannonian period (Poljak, 2017).

The Plio-Quaternary alloformations represent the youngest sedimentary units, indicating the onset of the latest terrestrial sedimentation processes in Slovenia. These deposits are predominantly composed of gravel, sandy gravel, and muddy sediments that are often pedogenised, reflecting a landscape heavily influenced by fluvial dynamics and terrace formation. They are present in all three units, south and north of the PAF and in Krško area (Ivančič et al., in review).

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Authigenic $^{10}Be/^{9}Be$ dating and provenance of Late Miocene deposits from the North Croatian Basin (Bozara section, SW Pannonian Basin System, Croatia)

During the Late Miocene in the North Croatian Basin (NCB), located in the southwestern part of the Pannonian Basin System (PBS), a several kilometres thick sequence, vertically arranged in a transgressive-regressive cycle, was deposited in Lake Pannon, a huge long-lived, endorheic brackish lake (Pavelić & Kovačić, 2018). The stratigraphic classification of these deposits was based on endemic fossil communities and is still a subject of great debate (Magyar et al., 2013). Recently, the authigenic 10Be/9Be dating method has been used for age determination of Upper Miocene and Pliocene deposits in the central and northern parts of the PBS (e. g., Šujan et al., 2016; Magyar et al., 2019), whereas in the NCB this method was only applied to a few samples from wells in the Drava depression (Špelić, 2023).

In the eastern part of the NCB, on the southern slopes of Mt. Papuk, a 27-meter-thick sequence of pelitic and sandy sediments rich in fossil molluscs and ostracods is exposed along the Bozara stream. Based on the sedimentological characteristics of the studied deposits and the identified benthic fauna, Mužek et al. (2023) showed that deposition took place during the Portaferrian (younger part of the late Pannonian) in a brackish lake environment. The deposits show a shallowing upward trend from deep-water sublittoral and distal prodelta settings to the deltaic shallow, high-energy, littoral environment.

The results presented herein report on the age of the investigated deposits using the authigenic 10Be/9Be radiometric dating method on 18 samples of pelitic sediments as well as the grain size and modal composition of four sand samples. The results obtained were used to reconstruct the provenance of the sandy detritus and the shelf margin of Lake Pannon.

Based on authigenic $^{10}Be/^{9}Be$ dating, the weighted mean age of the Bozara section is suggested to be 6.33±0.15 Ma. The results form a single population with an exception of one outlier. The grain size and modal analyses have shown that the sand is fine-grained and well-sorted. Its composition is dominated by quartz, muscovite and particles of older sedimentary or metamorphic rocks. Garnets, epidote and chlorites are the most abundant heavy minerals.

The suggested age of the Bozara section is within the time interval encompassing the Portaferrian (8.0–4.5 Ma) and can therefore be considered credible. The textural features and modal composition of the sediments at the Bozara locality are typical for detritus of Alpine provenance, which was transported into the NCB from the northwest by prograding fluvial systems during the regressive phase of Lake Pannon evolution (Sebe et al., 2020). Based on these results, we assume that the shelf margin of Lake Pannon was located in the area of the western part of Papuk at ca. 6.3 Ma.

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The integral approach of the subsurface facies interpretation, Drava depression, Croatia

For the petroleum industry, complex well analyses, especially for the basin-wide studies or regional subsurface interpretation, multi-disciplinary knowledge is crucial in delivering risk reducing results in acceptable time and cost consumption. Nowadays, the usual workflow combines 3D seismic attributes, well-logs, core data and all available geological information. Simultaneously, faster, closely specialized, and sophisticated software packages are created daily, and every new version needs even more specific and detailed data. Unexpectedly, that lead towards a process paradox. It is required to produce quality data in no time as cheap as possible from an inadequate or even lacking sample.

Very often the drilling campaign is planned to last an extremely short time. Consequently, a special PDC type drilling bit is used, which results in extremely small drill cuttings, often completely disintegrated lose sediments, increased borehole inclination and caving affect. Wire-line logging operations are reduced. Coring has become very rare, so the core data are missing.

Recently, three exploration wells Veliki Rastovac-1, Obradovci-1 Jug and Milkleuš-1 have been drilled in the Drava Depression on Drava-03 Exploration Block (DR-03).

Not nearly all the requirements of modern workflow were met during the drilling, but through multidisciplinary work, by combining different geological methods, the result of the research and post-drilling evaluation of the wells were quite satisfactory regardless the specifics of sample collection, caving, shredded small drill cuttings, no core samples, and no complete well-logging program.

Using petrographical, palynological, micropaleontological, geochemical and other specific analytical methods in the geological research laboratory, rock classification, mineral composition, provenance, mechanism, and place of sedimentation have been established. Also, the age of the sediments, marine, brackish, and freshwater paleoenvironments and paleoecology, facts about the type and content of organic matter in the palynological macerals have been defined.

In the geochemical assessment, the standard geochemical methods were performed. Organic geochemistry analyses were carried out to determine quantity, quality, and maturity of organic matter; special attention was paid to the optical parameters and biomarkers important in various depositional conditions and environment, and facies evaluation.

All obtained dana were combined with the borehole logging results. Conventional well logging was used for general lithology determination and correlation between wells. Resistivity image log interpretation and electrofacies analysis based on MRGC (Multi Resolution Graph based Clustering) methodology gave us a more detailed sedimentological insight into the drilled complex.

In the DR-03 Paratethys Neogene sediment succession starts after a long-lasting emersion, on a weathered and tectonised Palaeozoic-Mesozoic paleorelief with the continental syn-rift talus and alluvial fan deposits in the Ottnangian. Towards the Karpatian and during the lower Badenian, lake sedimentation took place. In the middle Badenian the first marine transgression occurred (PAVELIĆ & KOVAČIĆ, 2018; ĆORIĆ, 2009). The syn-rift tectonics lasted till the upper Badenian when post-rift sedimentation took place and the regression started. In the Sarmatian, the Paratethys become detached from the world's seas and turned into a brackish or even freshwater environment in places, which caused the vast extinction of stenohaline species and the appearance of the euryhaline organisms which very often exhibited endemism, making biostratigraphic analysis challenging and complicated. The boundary between the Middle and Upper Miocene is characterized by a continuous transition or marked by a hiatus. Lake

Pannon, that has flooded the whole Drava depression, locally developed brackish shallow-water calcite-rich marls, the first sediments in the Upper Miocene succession. As a result of the rapid subsidence, a deep depositional setting was formed, in which the open lake sediments were deposited. At first sporadically and then more often distal turbidites entered the basin floor as the most distant part of the large delta system that proceeded through the Drava basin, triggering facies progradation both in terms of space and time. After distal, proximal turbidites has been deposited. Turbiditic series have been overlayed by the slope toe subaquatic fan deposits followed by the slope pelites and finally shelf/deltaic bodies which towards the younger sequences (upper Pannonian and Pliocene) were formed in freshwater and shallow environment in which specific green algae prevailed. The youngest sediments (Pliocene-Quaternary) were commonly represented by the gravels, sand, silt clay and coal.

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The insight on subsurface facies analysis and related depositional environments, Drava depression, Croatia

A new well (Milkleuš-1) has recently been drilled in the scope of the Block DRAVA-03 exploration. Despite all the difficulties and efforts to save time and money, multidisciplinary work combining laboratory petrographical, palynological, micropaleontological, geochemical and other specific analytical methods with the borehole logging geophysical data, exchange of information, correlation and evaluation of each data set, synthesized results and detailed subsurface facies classification of the Pre-Pannonian and Panonnian depositional environments have been achieved.

In general, the Neogene sediment succession of the Drava depression started in the Ottnangian with the continental syn-rift talus and alluvial fan sediments created by rock-falls and fluvial mechanism, deposited on a weathered and tectonized Palaeozoic-Mesozoic basement.

Pre-Pannonian deposits in Drava-03 exploration area are composed of polymictic brecciaconglomerate, calcareous sandstones, siltstones, and mostly calcareous marl. In the observed area breccia conglomerate, pebbly sandstone to sandstone, marls, carbonate shales enriched with organic matter, dominantly of terrestrial origin, (kerogen type III), have been detected. Green algae *Botryococcus* sp. and *Pediastrum* spp. were found indicating Karpatian to lower Badenian continental environment with freshwater lake deposits and most possible some alluvial or deltaic sediments. Subsequent marls, limestones, calcarenaceous/calcarenite sandstone and pebbly sandstone indicate the first marine transgression in the area. Biostratigraphical association, which points to the middle Badenian age, is made of dinoflagellate cysts, benthic and planktonic foraminifera.

Gradual deepening of the depositional environment resulted in sedimentation of more fine-grained lithologies enriched with organic matter. In the biostratigraphical association planktonic foraminifera prevail over the benthic forms.

The organic matter content of the Middle Badenian sediments varies. Marls and carbonate shales show evidence of amorphous organic matter with a mixed origin (kerogen type II-III).

The syn-rift phase slowly weakened and lasted until the upper Badenian when post-rift sedimentation took place and the regression started. The deep marine environment progressively become shallower thus shelf, peri reef and littoral sandstone (calcarenaceous/calcarenites), limestones of the mudstone type and marls, carbonate shales enriched with organic matter) sediments occurred. Biostratigraphical association combines benthic foraminifera, less planktonic foraminifera and ostracods, bryozoans and urchin spines. The established planktonic and benthic foraminifera indicate Upper Badenian age of deposits deposited in a shallower marine environment.

The shallowing of the depositional environment continues through the uppermost Badenian and in the Sarmatian, when Paratethys become detached from the world's seas causing significant environmental change from marine into brackish and freshwater settings. Consequently, the stenohaline organisms become extinct and the euryhaline organisms took over. The most successful were *prasinophytes*, an opportunistic cosmopolitan group of unicellular green *algae* that prevail in the new paleoenvironment. As a result of their exceptional abundance, the uppermost Badenian to Sarmatian calcareous marls and shales are source rocks with good to very good generative potential in which kerogen type II dominate.

An additional difficulty is represented by the fact that due to the isolation of the Paratethys, pioneer species very often showed endemism, which made biostratigraphic analysis challenging and complicated. However, by comparison with the molluscs biozonation, the palynozonation and division of the Pannonian sediments have been made based on phytoplankton (mostly dinoflagellate cysts).

The first Upper Miocene sediments were formed in the Lake Pannon. Marls, clayey limestone and locally developed brackish shallow-water calcite-rich marls deposited in somewhat restricted settings are *biostratigraphically* affiliated to the lowermost Pannonian *palynozone Spiniferites pannonicus/Mecsekia ultima*, by the findings of the homonymous dinocyst and prasionphyte species.

As a result of the rapid thermal subsidence, a deep depositional setting was formed, and open lake sediments were deposited. On the basin floor entered first distal and then proximal turbidites followed as the most distant part of the large delta system that proceeded through the Drava basin, causing facies progradation (space, lithology, time). Those deeper water marls, siltstones and sandstones belong to the subsequent Pannonian *palynozones Spiniferites oblongus, Pontiadinium pecsvaradensis* and *Spiniferites balcanica* zone. Turbidites were overlayed by the slope toe subaquatic fan deposits. The slope pelites of upper Pannonian *Galeacysta etrusca palynozone* followed.

According to pyrolytic and optical maturation parameters, the organic matter in the entire well profile is immature. Low content of immature, autochthonous bitumen is extracted. Biomarker analysis indicates that the bitumen's origin and maturity are consistent with the associated kerogen.

The Pliocene muddy and clayey lake deposits and sand/sandstone shelf/deltaic bodies which towards the younger sequences were formed in freshwater and shallow environment of the Lake Slavonia become unfavourable for the dinoflagellates hence only freshwater green algae prevailed. The youngest sediments of the succession were made of Pliocene-Quaternary gravels, sand, silt, clay, and coal.

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Progress in dating and biozonation of the Sarmatian s.l. Stage in the Eastern Paratethys

The Eastern Paratethys is a former epicontinental basin that unified the Black Sea, Caspian Sea and the Dacian Basin and played a crucial role in shaping the west Eurasian paleoecosystems. In the late Middle–Late Miocene, during the Sarmatian sensu lato Stage (12.65 – 7.65 Ma), the Eastern Paratethys became hydrologically isolated from the global ocean. This process was accompanied by the adaptation and radiation of endemic faunas in the Volhynian and Bessarabian (early and middle Sarmatian s.l., respectively) and by the near complete extinction of aquatic life forms in the Khersonian (late Sarmatian s.l.). Despite a relatively clear understanding of the faunal trends during the Sarmatian s.l., neither faunal biozonation nor reliable age constraints yet exist for the Sarmatian s.l. substages. This complicates the intrabasinal correlation and hampers our understanding of the drivers of biotic demise and paleoenvironmental and hydrological perturbations in the Eastern Paratethys. Here, we present a synthesis of integrated stratigraphic data from three geological outcrops across the Eastern Paratethys: Jgali (Georgia, Black Sea Basin), Nadarbazevi (Georgia, Kura Foreland, Caspian Basin) and Karagiye (Kazakhstan, Caspian Basin). With the new data on the paleomagnetic dating, mollusc, ostracod, foraminifera and nannoplankton biostratigraphy of the Volhynian, Bessarabian and Khersonian (sub)stages we will highlight the progress and challenges of dating and biozonation of the Sarmatian s.l.

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New findings of genus *Creusia* Leach, 1817 (Cirripedia: Pyrgomatidae) in the Badenian deposits of the Banovina region (Croatia)

The Banovina region represents the southwestern edge of the Pannonian Basin System, which was covered by the Paratethys sea during most of the Badenian. The Cepeliš locality is situated 5 km southwest of the town of Petrinja and the studied succession consists of Paleogene clastics which are transgressively overlain by the Badenian Leitha limestone. Above the transgressive boundary ten specimens of barnacle belonging to the Creusia genus were found.

Fossil findings of genus Creusia in Croatia were previously reported only from the Badenian Leitha limestones of the Dvor locality in the Banovina region and Podsused area near Zagreb (Baluk & Radwanski, 1967). Our finding represents large fossil assemblage of this genus in the Badenian of the Paratethys sea.

Creusia barnacles, as other pyrgomatids, are characterized by a symbiotic relationship with scleractinian corals (Yap et al., 2023). Organic matter produced by coral zooxanthellae represents one of the carbon sources for the barnacle, while, in return, they provide ammonium for zooxanthellae (Brickner et al., 1997). However, our specimens are not preserved within their host corals (cf. Baluk & Radwanski, 1967), probably due to the dissolution of the corals' aragonitic skeletons.

Since they indicate a subtidal coral-reef environment, these fossils are useful for paleoecological reconstruction. Even though they live in a high-energy environment, their shells are not disarticulated, suggesting their preservation in situ. These findings, together with the ongoing studies of the Cepeliš locality deposits, will help in determination of the paleoenvironments of the southwestern part of the Paratethys sea during the Badenian epoch.

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Middle Miocene endemic mollusks from the Dinarides Lake System: a case study from the Bugojno Basin in Bosnia and Herzegovina

During the Middle Miocene, the Dinarides Lake System (DLS) was a major hotspot of freshwater mollusk diversity in southeastern Europe (Neubauer et al., 2015a). The numerous intramontane lake basins, originating from combined effects of tectonic subsidence and humid climate, accumulated thick lacustrine successions (de Leeuw et al., 2012). Due to diagenetic overprint and leaching of these carbonate-rich deposits, insights into faunal contents have been restricted to only a few basins up to the present (Neubauer et al., 2015b). We contribute to fill this gap by documenting for the first time a mollusk fauna from the Bugojno Basin in Bosnia and Herzegovina.

The succession is excellently outcropped in the open-pit coal-mine Gračanica NW Gornji Vakuf-Uskoplje. The fauna originates from a coal-bearing succession representing the gradual flooding of coastal wetlands followed upwards by the establishment of perennial lacustrine settings. Additionally to the mollusks, the succession comprises an exceptionally rich fossil record of terrestrial and aquatic fauna and flora, making it an important spot on the route for terrestrial mammal migrations from Africa and Asia Minor into Europe (Göhlich & Mandic, 2020).

The mollusk fauna of Gračanica comprises 14 limnic and 5 terrestrial species. Their distribution in the 40-m-long succession allows to detect paleoenvironmental changes during the history of Lake Bugojno. Terrestrial species are restricted to the coal-bearing lower part of the succession representing swamp and marsh deposits. Transitional deltaic cross-beds are associated with a peak in melanopsid gastropod abundance, whereas the subsequent establishment of littoral and sublittoral conditions is marked by a dominance of dreissenid and sphaeriid bivalve species. The overlaying interval, which seems to reflect profundal depositional environments of Lake Bugojno, is barren of mollusks. A short-term shallowing trend, recorded in the topmost part of the section, coincides with the occurrence of shell accumulations marked by peaks in species richness contributed by melanopsid, hydrobiid and neritid gastropods, along with the dreissenid bivalves.

The present taxonomic evaluation proved the species-level identifications from previous studies incorrect, resulting in a completely new understanding of the stratigraphic and paleobiogeographic significance of the Lake Bugojno mollusk fauna for the DLS evolution. In particular, the fauna shows a low level of similarity with other DLS basins, matching the general pattern of interbasinal dissimilarity detected by previous taxonomic studies. Such a pattern cannot be explained by different depositional conditions as the discussed mollusk fauna derives from very similar paleoenvironments of coal-bearing successions. At least parts of this taxonomic dissimilarity in the various DLS basins might have been caused by their isolated geographic settings, exampled by the recent regional diversity hotspot Lake Ohrid. The distribution of biostratigraphic marker species suggests an age younger than 15 Ma, pointing out the Lake Bugojno fauna as the youngest Middle Miocene mollusk-bearing horizon in the DLS.

In summary, our taxonomic analysis documents 17 gastropod and two bivalve species. New to science are three species attributed to the genera Prososthenia, Bania, and IIlyricocongeria. A paleoecological analysis based on quantified samples shows distinct shifts in mollusk composition and abundance. The terrestrial taxa are restricted to the coal-bearing interval of the section; melanopsids, neritids and hydrobiids are abundant in deltaic and littoral settings, whereas bivalves are frequent in littoral and sublittoral environments. In line with previous results, which have evidenced a high degree of intralacustrine radiation in the DLS, the Lake Bugojno fauna shows a low to moderate level of similarity to other DLS faunas. The dissimilarity may partly also result from its younger age, as suggested by the presence/absence pattern of regional biostratigraphic markers.

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Badenian Ostracods of North-Eastern Krško Basin

The Krško basin, located in the southeastern part of Slovenia, was and continues to be an area of several investigations and studies (Poljak et al., 2016; Poljak, 2017). One branch of these studies that holds quite significant weight in the understanding of the whole area is paleontology Organisms that were investigated were molluscs, ostracods, and foraminifera (Poljak, 2017). The previous ostracod studies were mostly focused on the Pannonian deposits, as other ages were determined on the basis of foraminifera or sedimentological analyses.

In the studied area of the North-Eastern Krško basin, we found a rare and Badenian ostracod fauna previously undocumented in Slovenia. As previously mentioned, the emphasis of ostracod research in Slovenia was on Pannonian deposits so this find is an important one as it allows us to better understand the biostratigraphic and geographic distribution of ostracods in Slovenia and Central Paratethys.

The marine ostracod assemblages consist of mixed deep-marine and shallow-water species: Aurila haueri, Aurila sp., Bairdoppilata cf. subdeltoidea, Bosquetina carinella, Bunonia dartonensis, Buntonia subulate, Cytherella cf. compressa, Cytherella parallela, Cytheropteron vespertilio, Ghardaglaia cf. pectinate, Henryhowella asperrima, Loxocorniculum hastata, Olimfaluina plicatulla, Parakrithe cf. crystallina, Parakrithe dactylomorpha, Paranesidea brevis, Phlyctenophora affinis, Pterygocythereis calcarata, Semicytherura galea, Xestoleberis dispar, Xestoleberis tumida.

Some species that were found are not constrained to the Badenian. Ostracod assemblages indicate lower to middle Badenian age of the investigated sediments.

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Neogene coals of Slovenia

Neogene coals in Slovenia (Markič et al., 2007; and references therein) occur it two basic paleogeographic and tectonic realms: as paralic coals in the periphery of the SW part of the Pannonian Basin System and as coals in intramontane basins within the Dinarides (Fig.). The first two are represented by coals in NE Slovenia in the Mura-Zala Basin (best explored in the Lendava – Petišovci - Benica area) and by coals in the Krško Basin (best explored in the Globoko area). Neogene intramontane coals occur in the Velenje, Krmelj, Kočevje, Kanižarica and Ilirska Bistrica basins.

All Neogene coals in Slovenia are lignites of predominantly huminite maceral composition. The highest coalification-rank lignites are those of the Mura-Zala Basin. In the deepest parts, below cca. 1000 m, they transit to meta-lignites due to well-known increased geothermal gradient. Most Neogene lignites of Slovenia are low grade coals with 20–30 mass % ash yield (dry basis), with 1.0–2.6 mass % sulphur content (dry basis), and calorific value in a range of 10.0–13.3 MJ/kg (at the "economic" as received basis). Exceptions are the Kočevje lignite with 4.5 mass % of sulphur and calorific value 14.6 MJ/kg, and, on the other hand, the Ilirska Bistrica lignite with only 6.2 MJ/kg calorific value. The lowest grade lignite is the Krmelj one with 35 mass % ash yield.

Diagenesis from peat to lignite ran predominantly in alkaline (Ca-rich) paleo-environments due to prevailingly pre-Neogene carbonate rocks in the hinterland, and carbonate fine clastics compacted to different degrees (clayey silts/siltstones, silts/siltstones, fine sands/sandstones, and "marlstones") in vertical and lateral vicinity of the lignite seams. Silicious component generally increases with increasing coarsening (middle and coarse sands/sandstones). Thrue clays are subordinated and so are conglomerates. Alkaline environments enhanced bacterial activity favourable for both reduction of sulphates to sulphides and acceleration of biochemical processes of transformation of organic matter from original heterogeneous vegetal material to more uniform one. This process, also known as biochemical gelification, affected fine organic detritus easier and earlier than bigger wooden pieces.

Paralic lignites of the Pannonian Basin are developed as numerous lignite seams (15–20) from some centimetres to 2.2 meters thick within 125 (Petišovci) to 175 (Globoko) meters thick sediments of the upper Pannonian (formerly "Pontian") age. Lignite-bearing sediments are freshwater, while sediments between lignite-bearing sequences are brackish. A distinctive sedimentary cyclicity occurs between the lignite seams, with the coarsest sediments (sands) approximately in the middle of them.

Numerous coal seams were detected throughout the Mura-Zala Basin by hydrocarbons wells, but not proved exactly by core drilling data. Deep coals (>800 m) of this basin represent a huge potential for e.g. carbon sequestration.

Paralic coal deposits are tectonically simple, the Petišovci considerably more than the Globoko one. Their present tectonic structure is a consequence of compressional regime and related basin inversion during the Pannonian times up to the present.

Intramontane lignite-bearing basins are tectonically more complicated, also exhibiting a final compressional regime. Lignite beds are less numerous but thicker, up to 7 metres, in Kočevje some of them even much more. Such a variability can be explained by different original peat thicknesses, their differential compaction and different contribution of mineral-rich intersediments.

Intramontane basins are filled by freshwater sediments. Defining the exact age is more complicated than in the case of paralic coals. Among the best results were obtained by pollen analyses.

Both the Kočevje and Kanižarica coals are known by high radioactivity (e.g. uranium content in the Kanižarica coal 250 μg/g comparing to ca. 3 μg/g in "world coals"), interestingly, especially in the lower-most beds close to the Mesozoic carbonates. Increased radioactivity is also well known for many Ca-rich coals in the Dinarides, but of Paleogene age (e.g. Vremski Britof, Sečovlje, and Raša).

The Velenje ortho-lignite seam is among the world coal-thickness phenomena with its thickness of up to 100 meters, extremely to 160 m. It occurs approximately in the middle of a 1000 m thick Pliocene to Quaternary clastic sedimentary sequence filling a typical pull-apart intramontane basin close to the Periadriatic Lineament.

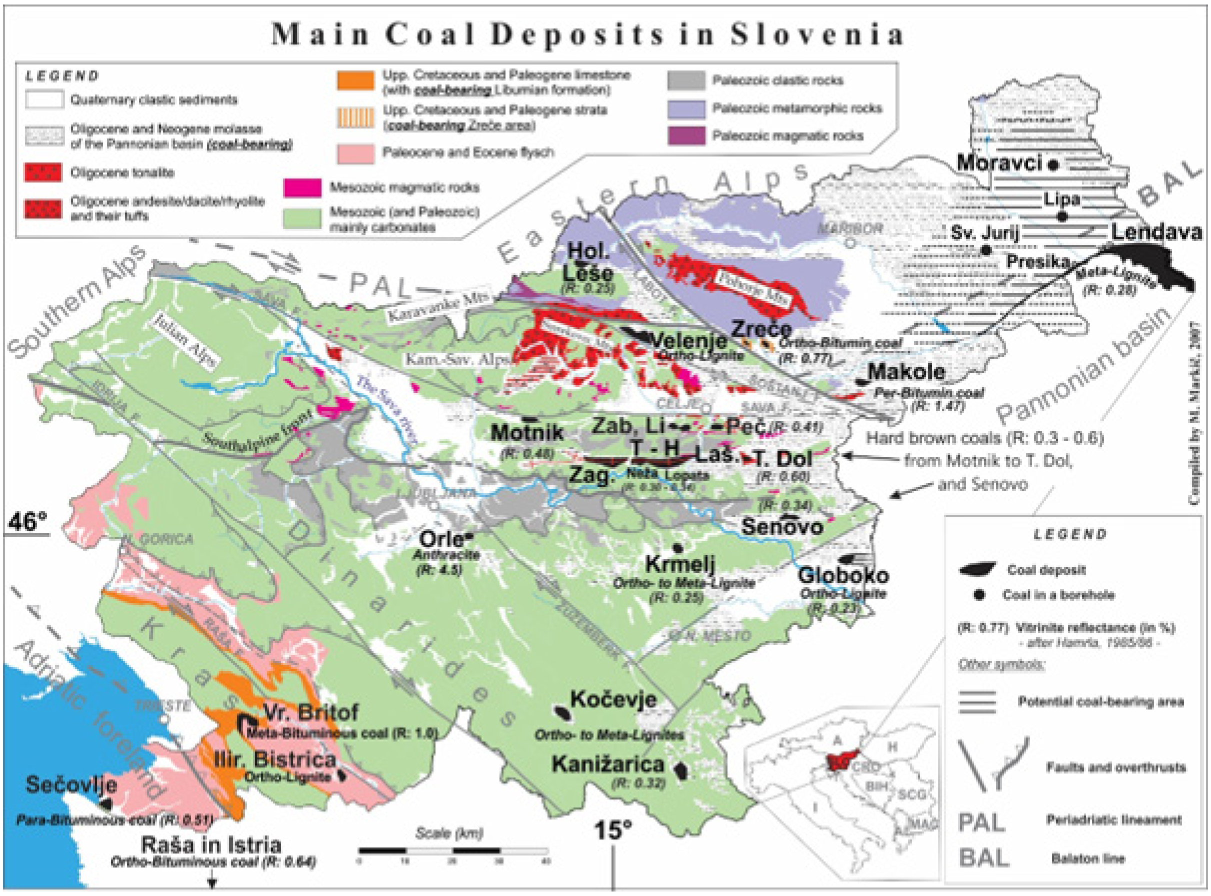

Figure:
Neogene lignites in this map are the following: paralic Lendava and Globoko and intramontane Velenje, Krmelj, Kočevje, Kanižarica and Ilirska Bistrica.

The Ilirska Bistrica lignite is only one single less than 5 m thick low-grade mineral-rich lignite at a depth of cca. 70 m. It is of a negligible economic value but was explored and also exploited between 1930 and 1950. High-quality clays are deposited above it up to the surface.

Arsenic (As) content is outstanding for the Pannonian Basin lignites in Slovenia. Only a few analyses involving As content were done but all indicate high contents – above 100 µg/g in "whole coal" samples – extremely to 390 µg/g in the Murska Sobota Sob-3g well in comparison to 7.6 µg/g for the world coals.

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The first results of paleoecological interpretation of the Middle Miocene sediments in the North Croatian basin based on smaller benthic foraminifera, Case study: Striježevica borehole, Papuk Mt.

The Papuk Mountain and Psunj, Krndija, Dilj, and Požeška Gora Mts. represent an isolated inselberg ring known as the Slavonian Mountains in the southern Pannonian Basin. The Striježevica borehole was drilled on the southern slopes of Papuk Mt. The sedimentary sequence, 95 meters thick in total, was lithologically described, with certain intervals selected for detailed micropaleontological and palynomorph analyses. The sedimentary sequence consists predominantly of marly sediments, with frequent sandy intercalations and a few limestone intercalations. A total of 84 samples were collected at 1 m resolution. We combine quantified records of foraminifera and palynomorphs with unquantified records of ostracods and nannoplankton to produce an accurate stratigraphic and paleoenvironmental reconstruction.

Paleoecological analyses based on smaller benthic foraminifera, so far, show three distinct phases in the depositional evolution of the sedimentary succession. The lower part of the succession, dominated by infaunal species indicates nutrient-rich environments in the water depth at the lower boundary or even below the photic zone (Hudačkova et al., 2020; Kranner et al., 2021). A decrease in oxygen supply, as amplification of environmental stress is detected by the highest proportion of dysoxic taxa, the decreasing trend of Fisher α and Shannon-Wiener index values together with the increasing trend of Dominance index values. These trends and the composition of smaller benthic assemblage indicate eutrophication (Baldi, 2006; Baldi & Hohenegger, 2008). Mesotrophic conditions in the middle part of the succession could be described as "a transitional environment", leading to the oligotrophication in the upper part of the succession. Three independent methods; P/B ratio, modified P/B ratio (after van der Zwaan (1990), and gradient analyses (Hohenegger, 2005 and Baldi & Hohenegger, 2008) were used to describe depositional (water) depth. Estimated depth ranges from the middle shelf to upper bathyal environments. All applied methods show a shallowing (regressive) trend upward which is also confirmed by an increase in oxygen content at the sea bottom, lower species richness, and, a decrease in diversity indices but an increase in dominance in the benthic foraminiferal assemblage (Mandic et al., 2019).

The nannoplankton zonal marker *Sphenolitus heteromorphus* Deflandre is present along the entire section indicating deposition during the NN5 Zone. According to the Croatian dinoflagellate zonation (Bakrač et al., 2012) the sediments of the Striježevica borehole can be correlated to the Uaq Interval Zone (*Unipontidinium aquaeductus*). The composition of the foraminiferal assemblages attributed the studied sediments to the Lagenidae Zone, and thus, also confirm the Middle Miocene age.

This research was conducted in the scope of the internal research project „RAMPA -Razvoj miocenskih paleookoliša na prostoru Hrvatske i njihova povezanost s globalnim događajima"at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia."

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Exploring the lacustrine ostracods and mollusks: preliminary results of the Kongora section (Tomislavgrad Basin, Dinarides Lake System)

During the Miocene, a multitude of intra-montane basins emerged within the Dinarides mountain range. These basins were characterized by the development of a series of long-lived lakes, collectively referred to as the Dinarides Lake System (DLS), which harbored endemic lacustrine fauna (de Leeuw et al., 2011; Krstić et al., 2003).

The Livno-Tomislavgrad basin in Bosnia and Herzegovina hosted one of the principal lakes within the DLS. The basin infill of lacustrine sediments is separated into two distinct lake phases corresponding to the evolution of the basin. The first phase denotes a period when the basin remained undivided, hosting the long-lived Lake Livno. Subsequently, during the second phase, separate lakes formed within the divided Livno and Tomislavgrad basins (de Leeuw et al., 2011; Papeš, 1975; Kochansky-Devide & Slišković, 1978, 1980).

The initiation of the second lake phase started with the deposition of white marls in separate lakes – Livno and Tomislavgrad. Two distinct lithological units characterize the uppermost strata of deposits from the second phase. The first one comprises a coal series, characterized by alternating layers of lignite and clays, while the second unit consists of a variegated series composed of layers of clays and sands with frequent limestone concretions (Papeš, 1975).

The Kongora section, which can be correlated with the second unit overlying the lignite layers, is situated at the eastern margin of the Tomislavgrad Basin, approximately 11 km southeast of Tomislavgrad. This 2-m-thick section is located on the eastern bank of the Rudnik Lake and comprises a succession composed primarily of silty clay and poorly sorted conglomerate. Five sediment bulk samples were extracted from the section. The mollusk fauna is represented solely by fragmented remains of minute shells including among others sphaeriid bivalves (Pisidium sp.) and planorbid (*Gyraulus* sp.) gastropods indicating fresh-water depositional setting.

In the analyzed samples, the freshwater ostracod fauna was documented, representing three distinct families: *Candonidae* (Kaufman), which includes *Candona neglecta Sars*, *Candona* sp., and *Fabaeformiscandona*? sp.; *Cyprididae* (Baird), encompassing *Scottia browniana* (Jones) Brady & Norman, and Scottia sp.; and Ilyocyprididae (Kaufman), with the presence of *Ilyocypris* cf. *bradyi* Sars.

The identified *Ilyocypris bradyi* has been documented from the Miocene, Pliocene, and Pleistocene and is still living now. This discovery underscores the remarkable longevity and evolutionary constancy of *I. bradyi* within aquatic environments (Meisch, 2000). Conversely, species such as *Candona neglecta* and *Scottia browniana* have been documented from the Pliocene to the Pleistocene (Van Baak et al., 2013; Sokač, 1978).

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Challenges and Insights: Sequence Stratigraphy of Pannonian Coals in the Drmno Depression, Serbia

The application of sequence stratigraphy on coal beds worldwide has significantly contributed to the understanding of coal deposits and their origin. On the southeastern edge of the Serbian part of the Pannonian basin, there is a system of peri-Pannonian basins characterized by the appearance of Upper Miocene coal seams in the siliciclastic fill, which provides an excellent opportunity for testing sequence stratigraphy in young coal basins. In this study, sequence stratigraphy was applied to coals in the Drmno Depression, which presents a challenge to traditional prospecting methods due to its lack of lateral continuity.

The deposition of siliciclastics was formed in the upper delta plain, which then transitioned into alluvial channels with segments of swamps where peat accumulated. The accumulation of peat and siliciclastics was cyclical, from the geometry of the layers, it is evident that the center of peat accumulation moved vertically, due to the inability of horizontal expansion as a result of the developed vegetation (Gradzinski et al., 2003).

Four sedimentological units were distinguished based on geophysical logging data, seismic profiles, and field data. The sedimentation cycle of each unit commences with fine-grained siliciclastics of the upper delta plain, followed by coarse-grained siliciclastics of alluvial channels, and ends with the accumulation of peat and the formation of coal. The units located in the deeper parts of the basin were determined by using overlapping seismic data and geophysical logging data. However, only the upper part of the second unit was visible on the open section, so they are classified as assumed. On the other hand, the third and fourth units are located in shallower parts and were defined based on both well data and field data from open sections and are therefore classified as certain.

The age of the youngest sedimentological unit was determined by biostratigraphy, based on the different species of *Prosodacnomya bivalva*. The discovery of *Prosodacnomya carbonifera* in the southern region revealed an age of 7.5-8 million years (Radivojević et al., 2022), while the discovery of P*rosodacnomya elongata* in the northern part indicated an age of 7.2 million years (Radivojević et al., 2022).

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Biostratigraphy of middle Miocene deposits overlying and underlying the Outer Carpathians based on calcareous nannoplankton – preliminary results

The studied N-2 well is located in the area of Rzeszów Bay in Southern Poland. The Middle Miocene deposits of Rzeszów Bay were formed as a result of the transgression of the Paratethys Sea onto the eroded margin of the Outer Carpathians (Kotlarczyk 1991). Due to orogenic movement, the Carpathian deposits, together with the overlying transgressive Miocene deposits, were overlapped on the area of the Outer Carpathian Foredeep. In the N-2 well, the transgressive Miocene deposits of Rzeszów Bay (claystones interbedded with sandstones) are located at a depth of 21 – 540 m, while the autochthonous Miocene deposits of the Carpathian Foredeep (claystones) are located at a depth of 3260 – 3315 m. The examined samples were taken from the drilling core at depths of 520 – 526 m and 3270 – 3274 m, 3276 – 3285 m, 3290 – 3299 m, 3303 – 3309 m and 3312 – 3315 m, thus comprising both transgressive and autochthonous Miocene deposits.

Calcareous nannoplankton assemblages in the Middle Miocene deposits within the studied geological column exhibit limited taxonomic diversity. The samples from the autochthonous Miocene and the transgressive Miocene deposits are dominated by *Coccolithus pelagicus* and small *Reticulofenestra species*. *Cyclicargolithus floridanus*, *Reticulofenestra pseudoumbilicus* and *Helicosphaera carteri* occur in smaller numbers. The samples also include: *Calcidiscus leptoporus*, *Calcidiscus premacintyrei*, which have been recorded in samples from autochthonous Miocene only, *Umbilicosphaera jafari*, *Reticulofenestra perplexa*, *Helicosphaera carteri* var. *burkei*, *Helicosphaera walbersdorfensis*, *Sphenolithus abies*, *Sphenolithus moriformis*, *Pontosphaera multipora*, *Braarudosphaera bigelowii*, *Thoracosphaera saxea*. No well-preserved specimens of *Discoaster*, important for Miocene biostratigraphy, have been found in the studied samples. The relatively rare occurrence and poor preservation state of discoasters in the Carpathian Foredeep deposits are known from the previous research (e.g. Garecka 2014, Oszczypko-Clowes et al. 2012). The stratigraphically important *Sphenolithus heteromorphus* is present in samples taken from the autochthonous Miocene deposits. Single specimens also occur in a few samples of transgressive Miocene deposits. All samples also contain reworked Paleogene and Cretaceous taxa, mainly: *Coccolithus formosus*, *Cyclicargolithus abisectus*, *Reticulofenestra bisecta*, *Reticulofenestra lockeri*, *Reticulofenestra reticulata*, R*eticulofenestra umbilicus*, *Watznaueria barnesiae*, *Micula staurophora*.

Biostratigraphic conclusions were based on Martini's (1971) zonation: the NN4/NN5 boundary was determined by the last occurrence of *Helicosphaera ampliaperta*, while the NN5/NN6 boundary was established by the last occurrence of *S. heteromorphus*. Preliminary research results indicate that samples taken from autochthonous Miocene deposits belong to the NN5 zone sensu Martini (1971). In most examined samples, *S. heteromorphus* was recorded and no *H. ampliaperta* was found. It seems that samples from the transgressive Miocene deposits belong to the NN6 zone, although a few samples contain single specimens of *S. heteromorphus*. These may potentially be redeposited elements in deposits belonging to the NN6 zone. According to Hohenegger et al. (2014), the NN5 zone corresponds to the middle and late Badenian and the NN6 zone corresponds to the late Badenian and Sarmatian.

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Decoding the changes in Middle Miocene shelfal environments by studying foraminiferal assemblages: Bednja section (Hrvatsko Zagorje Basin, Croatia)

The Bednja section located in northern Croatia, near the town of Krapina, consists of marly deposits attributed to the Middle Miocene and originated in the Central Paratethys sea (Hrvatsko Zagorje Basin). Foraminiferal tests were obtained using the wet sieving method and analyses were performed on standardized samples (approximately 300 randomly selected specimens in the ≥ 63 µm size fraction) with the aim of paleoecological reconstructions of the environment (including paleobathymetry, salinity, concentration of organic matter and oxygen availability at the seafloor). For these objectives we addressed the following characteristics of foraminiferal assemblages: 1) the planktonic/benthic ratio (P/B ratio) (Murray, 2006); 2) dominant and common species of benthic foraminifera, their known ecological/paleoecological preferences (like known depth ranges, mode of life, food preferences); and 3) the values of diversity indices and Benthic Foraminifera Oxygen Index (BFOI) (Kaiho, 1996; Jorissen et al., 2015).

The values of the P/B ratio varied from 6.0 to 46.7%, showing oscillations along the section, indicating possible changes in the depth of deposition within the middle shelf setting. However, such changes in the P/B ratio can also be caused by selective dissolution of planktonic tests or fluctuations in the productivity of the upper part of the water column, i.e. changes in the quantity and quality of the nutrient flux to the seafloor.

Within benthic foraminiferal assemblages, five epifaunal, oxic species dominate. The relative abundances of species *Asterigerinata planoribis* d`ORBIGNY (18.7 – 29.8%), *Elphidium fichtelianum* d`ORBIGNY (8.5 – 16.7%) and *Elphidium crispum* d`ORBIGNY (5 – 10.9%) exhibit slight fluctuations along the section. The abundances of species *Cibicidoides ungerianus* d`ORBIGNY (12.8 – 45.3%) and *Lobatula lobatula* WALKER & JACOB (4.7- 20.3%) show significant variations that are considered a complementary relationship. Intervals with lower oxygen concentration on the seafloor (lower BFOI values) and a higher P/B ratio have a higher abundance of *L. lobatula* specimens, while intervals characterized by higher BFOI values and a lower abundance of planktonic foraminifera are dominated by *C. ungerianus* individuals. This relationship between the species *L. lobatula* and *C. ungerianus* indicates the existence of competition between them and their reaction to fluctuations in the quantity and quality of organic matter reaching the seafloor.

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Shelf-edge advancement in the southeastern perimeter of Lake Pannon, Banat (Serbia and Romania)

During the late Neogene period, the Pannonian Basin situated in Central Europe underwent a process of sediment deposition as rivers flowing from the Alps and Carpathian Mountains discharged their sediment loads into Lake Pannon (MAGYAR ET AL., 2013; BUDAI ET AL, 2019). The most prominent source-to-sink system was associated with the ancient Danube River, which transported sediments from the northern foreland of the Alps into the lake, causing a northwest to southeast progradation of the shelf-edge. In the southeastern border of the basin, however, localized sedimentary systems operated in the opposite direction, contrary to the prevailing north-to-south sediment flow (MAGYAR ET AL., 2013, TER BORGH ET AL., 2014).

The duration and rate of advancement of these counterflow systems were previously unknown. We conducted an investigation of one such sedimentary system in the southeastern region of Banat, at the southeastern tip of the Pannonian Basin (RADIVOJEVIĆ ET AL., 2022). This system transported material from the westernmost part of the Southern Carpathian Mountains toward the central region of the basin in the northwest.

Approximately 9.6 to 9.1 million years ago, following the inundation of the foothills of the Southern Carpathians by Lake Pannon, a shelf began to form, extending from the Southern Carpathians into the deep waters (300 to 500 meters) of the adjacent local depression. The expansion of the shelf-edge progressed to the vicinity of Vršac Island, which is situated about 20 to 25 kilometres to the northwest. This occurred approximately 7.5 to 7.0 million years ago, and during this time, a small-scale transgressive-regressive cycle developed on the flanks of the Vršac Mountains (Figure, RADIVOJEVIĆ ET AL., 2022).

This cycle involved the deposition of coarse-grained materials sourced locally during the initial flooding, which were subsequently covered by offshore marls that represented the peak of flooding. These layers were further overlain by a regressive deltaic sequence originating from the Southern Carpathians.

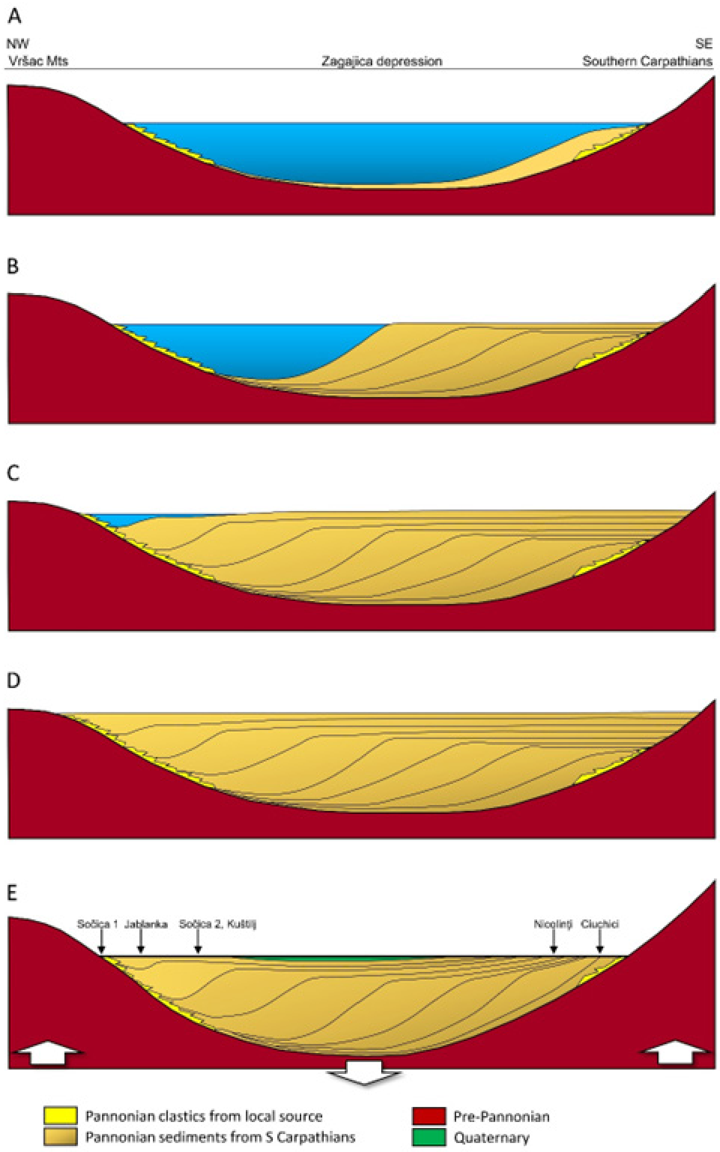

Figure:
Schematic representation of the evolution of the study area between the Southern Carpathians and the Vršac Mts across the Zagajica depression– A - Initial shelf-edge forms at the S Carpathians (9.7–9.6 Ma); B Shelf-edge progradation across the Zagajica depression (9.6–7.6 Ma); C Transgression on the flanks of the Vršac Mts (7.6 Ma); D Shelf-edge progradation fills the Zagajica depression and passes by the Vršac Mts (7.1 Ma); E Present-day conditions, formed by Quaternary basin inversion, deposition in the basin center and erosion on the flanks of the mountains (RADIVOJEVIĆ ET AL., 2022). verageverage rate of progradation of the shelf-edge, roughly around 10 kilometers per million years, was nearly an order of magnitude lower than the progradation rate observed in the contemporary paleo-Danube shelf located on the opposite northwestern side of the lake.

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Neogene Paleoenvironmental Dynamics: Insights from the Čerević Region in Northern Serbia's Fruška Gora

The northern Fruška Gora region holds paramount importance in deciphering the Neogene geological evolution of northern Serbia, particularly regarding the Miocene and Pliocene deposits associated with the evolution of the southern margin of the Pannonian Basin represented by significant environmental fluctuations driven by rapid shifts in abiotic factors. Furthermore, the scarcity of geological survey papers on Čerević (Radoičić & Jovanović, 2012) and its surrounding area (Ter Borgh et al., 2013) makes this article particularly valuable, as it provides new insights into the diversity of sedimentary environments, their interconnections which are represented by facial associations, and their evolution through stratigraphic and tectonic events.

Subsequent to field observations and data collection using standard protocols at fourteen designated field stops, the collected samples were forwarded to laboratories for further petrological and paleontological analysis. Utilizing software programs, the obtained data was plotted into geological logs corresponding to the Brazilija, Čerević, Erdelj brdo, Filijala, and Šakotinac sites. This in-depth analysis enabled the comprehensive understanding and interpretation of sedimentological facies across the temporal spectrum between early Miocene and Pliocene.

Our findings reveal a dynamic sedimentary record, highlighting the transformation of the Čerević area from typical lacustrine conditions in the early Miocene to marine environment during the Badenian. This transition was primarily attributed to the tectonic uplift of the Fruška Gora ridge and subsidence of its peripheral margins, leading to the transgression of middle Miocene marine waters. This transgression is evident from the predominance of carbonate facies and abundant marine fossils such as planktonic and benthic foraminifera, ostracods, bryozoans, red algae, corals and echinoids, suggesting shallow marine and warm conditions. Interbasin turbations observed in Badenian marls at the Erdelj site further support the possibility of carbonate slope proximity. The Sarmatian deposits continued to exhibit characteristics of shallow water, with a shift toward marl formations, indicating lower energy conditions in waters between marine and brackish salinity. Early Pannonian deposits exhibited features of a bottomset delta environment, characterized by alternating marl and silt formations deposited in caspi-brackish conditions which alternate toward continental environment formations in upper Pannonian. Accordingly, the Pliocene deposits display prominent fluvial characteristics, evident from common ripple structures, indicating unidirectional transportation and fluctuating flow regimes with occasional avulsion. Finally, the subsequent energy plunges led to the formation of bars and alluvial plains.

In addition to quantitative and qualitative analysis of satellite imagery, the study employed these methods to investigate neotectonics in the area (Figure) and generate reconstruction models putting an accent on slope stability with respect to erosion/accumulation rates and block movements. This data is further utilized as an indication of the possibility of future rupture activity and an understanding of the general safety of the area. In conclusion, the analysis exposes vulnerabilities in the southeastern region's stability, highlighting the crucial role of both intense erosion and active neotectonic structures.

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Facies associations of Middle Miocene (Konkian of Eastern Paratethys) sedimentary succession of the Kura Basin (Ujarma section, Georgia)

The Eastern Paratethys Konkian is correlated to the Kosovian (13.65–12.829 Ma) in the Central Paratethys and is related to the timing of last large Middle Miocene marine transgression in Paratethys (Hilgen et al., 2012; Hohenegger et al., 2012; 2014). The facies associations of the Konkian sedimentary sequence of the Ujarma section (Kura basin, Georgia, Eastern Paratethys), accumulated under different sedimentation regimes and reflecting the stages of marine transgression, are considered in this conference paper.

The Ujarma section is located on Eastern Georgia (Kakheti) (41°77'62.24" N, 45°14'95.65" E) and comprises well-exposed Konkian-Lower Sarmatian sediments. Sartaganian and Veseljanian sediments of the Konkian stage are defined in the Ujarma section. Total thickness of these sediments is approximately 69–73 m. The Konkian sediments consist of clays, separate sandy layers, as well as alternating clays with sands. The fine-pebble conglomerate occurs at the base of the Sartaganian. According to determinations of foraminifera by K.P. Koiava, these sediments containing Borelis melo (Fichtel & Moll) correspond to the Sartaganian (Layers 2–6); rocks containing Varidentella reussi sartaganica (Krash.) and species of genus Ammonia (Ammonia beccarii (Linnaeus) and others) correspond to the Veseljanian (Layers 11–18) (Rostovtseva et al., 2020). The Ujarma Konkian sedimentary succession is revealed as a facies association reflecting the influence of wave and subaqueous deltaic regimes of accumulation (Figure).

The wave dominated regime resulted in five major facies associations: (1) transgressive erosion facies association (TE), (2) upper part of sand sheets (SS1), (3) lower part of sand sheets (SS2), (4) middle shoreface (MS), (5) lower shoreface (LS). The first three facies accumulated within the upper part of the shoreface. The wave dominated facies are defined for the Sartaganian and the lower part of the Veseljanian. Accumulation of these sediments reflects the onset and maximum development of the marine transgression.

The subaqueous deltaic regime resulted three major facies associations: (1) lower front delta (FD), (2) upper prodelta (PD1), (3) lower prodelta (PD2). These facies associations are revealed for the Veseljanian and the Lower Sarmatian. These sediments accumulated mainly within the shoreface. At this time there is a wide development of subaqueous deltaic sediments against the background of stabilization and weakening of marine transgression.

The facies analysis of the Ujarma Konkian sedimentary succession reveals eight facies associations reflecting the change of depositional environment. The change of Konkian depositional environments was controlled by the stages of marine transgression, as well as by the progradation and lateral migration of the front delta and prodelta.

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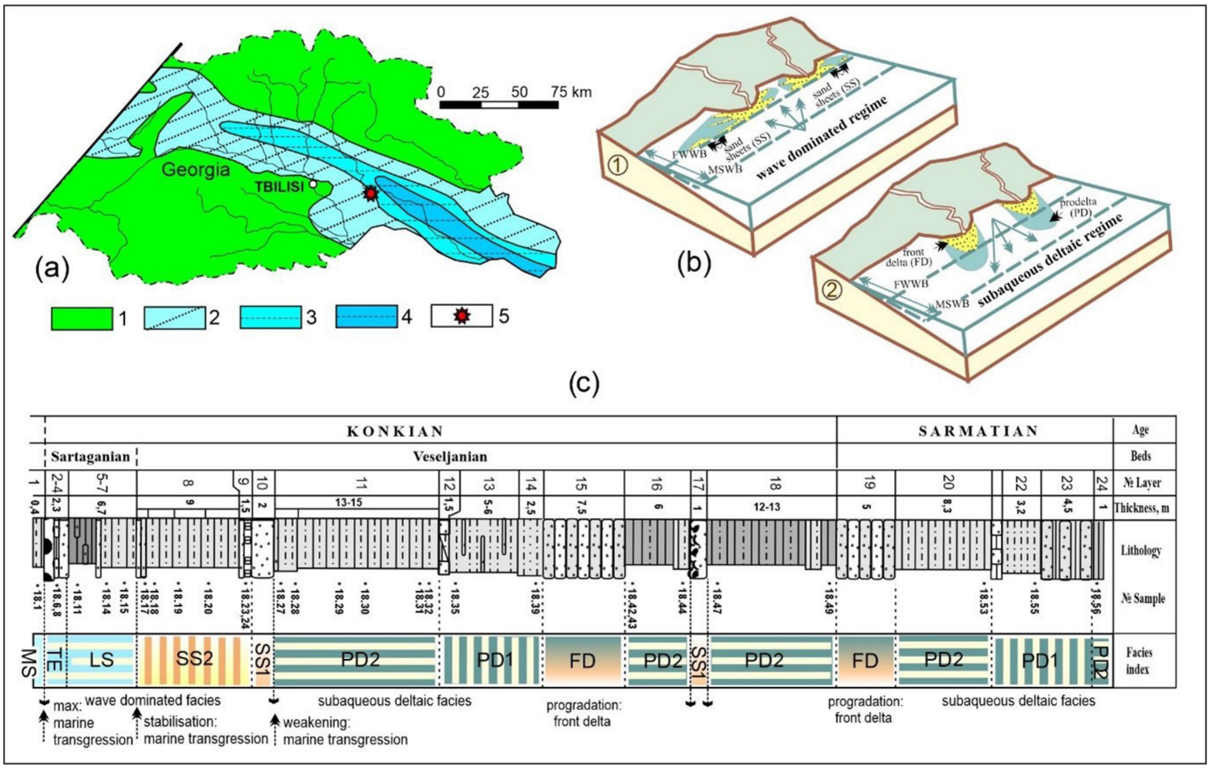

Figure:
Depositional environments and facies associations of the Ujarma Konkian sedimentary succession. (a) Depositional environments at the initial Sarmatian in the Kura basin, modified after (Koiava et al., 2012): land (1), shallow water (2), transitional (3), relatively deep-water (4) settings and location of the studied section (5); (b) models of the shallow-marine depositional environments of the Konkian rocks: wave dominated (Layers 1–10) (1) and subaqueous deltaic (Layers 11–18) (2) regimes, (FWWB) fair weather wave base, (MSWB) maximum storm wave base; (c) lithological column and facies associations: transgressive erosion (TE), upper part of sand sheets (SS1), lower part of sand sheets (SS2), middle shoreface (MS), lower shoreface (LS), lower front delta (FD), upper prodelta (PD1), lower prodelta (PD2).

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Fossils from the Upper Miocene (Pannonian) sands of the Pécsvárad sand pit (Eastern Mecsek Mts., SW Hungary)

The Mecsek mountains in SW Hungary are an uplifted basement block of the Pannonian Basin. Their Neogene cover includes deposits both from the Middle Miocene Central Paratethys and from its Late Miocene (Pannonian) brackish-water descendant, Lake Pannon. Along the mountain front, the Pannonian sands of the Pécsvárad sand pit contain a mixed vertebrate fossil assemblage, which gives insight into terrestrial and aquatic biota during various time intervals of the Miocene.

The fossil-bearing sands accumulated between 7.6–6.8 Ma, in a high-energy littoral setting of Lake Pannon, as indicated by the mollusc remains. The vertebrate fossil assemblage is relatively diverse compared to the number of finds. The most abundant group, aquatic mammals, including at least four odontocete species and a few mysticete taxa, originally lived in the Paratethys, during the Badenian and the Sarmatian. Rhinoceratid remains are reworked from sediments aged somewhere between the Karpatian and earliest Pannonian. The single shark tooth must be Badenian, and probably the scombrid fishes have that age as well. Fossils of other fishes (sparids, latids and acipenserids), giant salamanders, turtles, crocodilians and cervids might originate from older Miocene deposits but can be coeval with the host sands as well. Tapirs and giraffes must have lived on the lakeshores of Lake Pannon, probably contemporaneously with sand deposition or not much earlier. The erosion, enrichment and mixing of the fauna is a result of the uplift and denudation of the Mecsek mountains during Lake Pannon sedimentation, caused by neotectonic basin inversion.

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Macrofauna of the Lower – Middle Miocene lacustrine sediments of the Mecsek mountains, SW Hungary: preliminary results

Lakes formed in tectonic grabens related to the Miocene rifting of the Pannonian Basin have long been known in Serbia and Croatia, but they have only recently been identified in the Mecsek mountains in SW Hungary, where Karpatian–Badenian lacustrine deposits occur. Apart from a few endemic molluscs, the biota of these successions has not been studied in detail. Our research project 138638 funded by the Hungarian National Research, Development and Innovation Office aims at contributing to the knowledge on the poorly documented fauna of the lake sediments.

Lacustrine deposits were studied at more than a dozen locations, in surface outcrops and in a cave system. Macrofaunal remains were collected in the field during several campaigns. They often had a poor preservation and needed impregnation already at the outcrop. In addition, we sampled sediments for sieving, samples attaining about 10 l each. These were sieved after treatment with HCl and/or H_2O_2, in 1 mm mesh sieves. A rhinoceratid mandible collected earlier from the cave was also investigated.

The littoral deposits made up of locally sourced conglomerate, sand(stone), mollusc-bearing sand and limestone are classified into the Pécsvárad Member of the Kiskunhalas (previously Budafa) Fm. Their macrofauna is dominated by the bivalve *Congeria boeckhi* and the gastropod *Ferebithynia (Bulimus) vadaszi*, accompanied by 2-3 forms of small snails. Fish remains are ubiquitous, identifiable remains are Lates, Sparus and Siluriformes bones. Some outcrops contained abundant small Sparidae (*Diplodus, Sparus, Pagrus*) teeth. Sporadically, elongated or spherical vertebrate coprolites, turtle carapax fragments, crocodylian (*Diplocynodon*) bones, teeth and osteoderms, and bones of yet unidentified terrestrial mammals were found. The occurrence of a young sirenian (*Metaxytherium?*) humerus was unexpected. The rhinoceratid mandible belonged to an adult individual. The morphological features and the small dimensions of the teeth suggest an attribution to the genus *Lartetotherium*; this taxon is presently documented in central European localities between the Mammal Neogene Zone (MN) 4 and 9. Our specimen was found somewhat below a tuff layer dated to 16.8±0,65 Ma, thus it belongs to the MN4 zone.

The Komló Clay marl Member, which comprises the sublittoral lake deposits, is made up of clay marl, silt and sand, occasionally with coquina and lignite interbeds. Its mollusc fauna is identical to that of the Pécsvárad Member, and in addition it contains abundant gastropod opercula. Fish bones and teeth are common, among them those belonging to the Sparidae family. A part of the vertebra and fin bone remains represents the Latidae family. A turtle carapax fragment probably belonged to the pond turtle (*Emys*).

In the Eastern Mecsek mountains, black, brown or dark grey clay-silt-sand successions with plant remains, unionid bivalves, gastropod shells and opercula are classified into the fluvial Szászvár Formation. Based on the sedimentological features, these can be interpreted as lacustrine delta deposit. 3 - 15 m thick, coarsening upward packages represent shallowing upward cycles from the prodelta through the delta front to the delta-top fluvial sediments. Fossil-rich sandy facies most probably represent the lower delta front, where floods of the rivers discharging into the lake carried large amounts of terrestrial material, among others plant remains, and could also transport bivalves inhabiting the delta front. The rich but poorly preserved mollusc fauna contains at least 3 - 4 species of thick-shelled unionid bivalves and numerous gastropod taxa, the latter including typical freshwater ones (e.g. *Prososthenia*, *Theodoxus* spp.). Sieving residues are dominated by gastropod opercula, which show higher morphological variety than those of the Komló Clay marl. In addition to molluscs, fish bone fragments and teeth were found. Similar assemblages have been reported from the Dinaric Lake System, but there the taxa occurring in Hungary are accompanied by *Congeria* species.

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Hunting for the Paratethyan acorn barnacles (Cirripedia: Balanomorpha: Balanidae)

The acorn barnacles, inhabitants of the rocky seashores, comprise numerous extant genera, but are also known from the fossil record. They also represent one of the most common invertebrate encrusters on oyster shells. Their sessile modes of life lead to the specific anatomy of soft tissues and the development of a complex calcareous skeleton. Due to their habitat in high energy environment, complete fossils are not very common, but disarticulated plates can be found in soft sedimentary rocks and extracted from e.g. marls by the standard wet-sieving technique. Their complex microstructures can be also recognized from cross sections of consolidated rocks. Nevertheless, they are not particularly handy for biostratigraphical research and are therefore rarely studied in detail or even mentioned in the published papers.

The aim of this study is to present the findings from the Central/ Northern Croatia and give a clue to recognition of barnacles from thin sections.

Extracted barnacles (Figure a) and rocks comprising barnacle particles were collected in the field, at the Medvednica Mt. and Marijagorička Brda Hills near Zagreb (Croatia), from deposits of the Middle Miocene (Badenian) age. Cross sections were also recognized in the pebbles from the Quaternary gravels SE of Zagreb. Additionally, fossils from the Croatian Natural History Museum in Zagreb were also taken into consideration.

Thin sections were prepared from bioclastic limestones of the Badenian age and from the pebbles collected in the Sava River alluvial plane (Figure b). Diagnostic features were compared with the study of recent barnacle skeletons.

Acorn barnacles are the important proxies of the rocky shores and therefore deserve much more attention in the study of marginal marine deposits in the fossil record. We hope that this study will contribute to the better knowledge of this neglected fossil group.

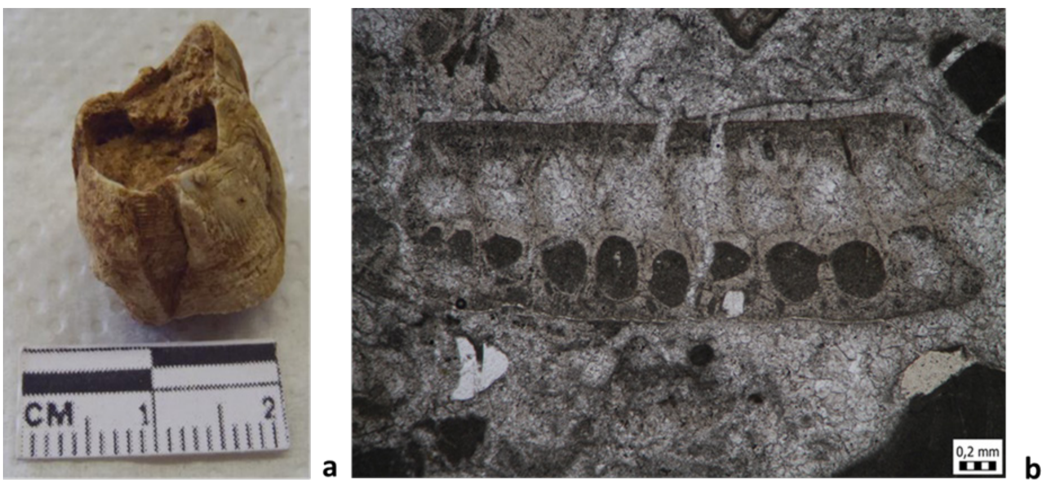

Figure:
(a) Miocene fossil barnacle Balanus vadaszi Kolosvary, 1949 found at the Marijagorička Brda Hills (NW from Zagreb) (Vadlja, 2018) and (b) photomicrograph presenting a cross section of a barnacle from the Miocene pebble in the Gravel pit Abesinija (SE from Zagreb).

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Pectinidae and Cardiidae from the middle Miocene of Poland – witnesses of environmental changes in the Paratethys

The Middle Miocene (Badenian–Early Sarmatian) is a time of significant climatic and paleogeographic changes in the Central Paratethys, a vast inland sea composed of several interconnected water bodies. After the Middle Miocene Climatic Optimum (MMCO) lasting until 14.7 Ma and the Middle Miocene Climatic Transition phase (MMCT), about 13.82 Ma, the temperature decreased significantly, which may have caused the regional extinction of most thermophilic organisms. Moreover, around 12.65 Ma there was a faunal crisis, called the Baden-Sarmatian Extinction Event (BSEE), which marks the Badenian/Sarmatian border. The reasons for this sudden decline in biodiversity should be seen not only in the interruption of the connection of the Central Paratethys with the Mediterranean area around 12.65 Ma, but also in the creation of wide connections with the almost three times larger Eastern Paratethys, whose waters were characterized by reduced salinity throughout most of the Middle Miocene, never reaching 25‰ (Nevesskaja et al. 2005; Studencka and Jasionowski 2011).

Bivalves are among the best recognised fossil invertebrates occurring in the Middle Miocene strata of the Central Paratethys. Knowledge of the species composition of bivalve assemblages within the Central Paratethys is of key importance for the reconstruction of paleoenvironment. To show how bivalves inhabiting the Fore-Carpathian Basin, being in the Middle Miocene the northernmost part of the Central Paratethys, responded to the above changes, the species composition of two families was analysed: Pectinidae (scallops), and Cardiidae (cockles).

The hitherto study revealed 30 scallop species in both the lower and upper Badenian sandy and carbonate deposits from Poland. The occurrence of 12 species is restricted to the lower Badenian. The lack of thermophilic scallops such as *Cristatopecten cristatum badense*, *Cristatopecten spinulosus attenuatus*, *Gigantopecten nodosiformis*, *Austrohinnites brussoni* and *Aequipecten opercularis* in the late Badenian assemblages from Poland is related to a significant progressive cooling of waters in the Fore-Carpathian basins compared to the Inner Carpathian basins of the Central Paratethys during the MMCT. From among 18 scallop species found in the upper Badenian deposits in Poland, the majority are remnants of the early Badenian fauna; only *Propeamussium felsineum*, *Parvamussium fenestratum* and *Palliolum bittneri* [=*Chlamys elini*], invaded the Fore-Carpathian Basin in the late Badenian. The appearance of the latter species in the Paratethyan Province is recognized as a distinct marker for reliable correlation of the uppermost Badenian and Konkian. None of the scallop species, like other marine stenohaline species, survived the environmental changes as a result of which the late Badenian basin was transformed into a highly isolated early Sarmatian basin with significant fluctuations in the salinity level (30–18‰), decreasing towards the east (Studencka and Jasionowski, 2011).

The Middle Miocene cockles from Poland are less diversified than the scallops (25 species compared to 30 species). During the maximum of the early Badenian transgression ca 15.1 Ma, which reached the southern slopes of the Holy Cross Mts., 11 cockle species appeared but only six of them survived until the late Badenian. The occurrence of thermophilic species *Procardium danubianum*, *Procardium kunstleri* and *Discors spondyloides* is limited only to the early Badenian. Eleven species of cockles have been detected in the upper Badenian strata of Poland. A characteristic feature of the early Sarmatian assemblages is high frequency of the subfamily Lymnocardiinae, represented by three endemic genera – Inaequicostata, Plicatiforma and Obsoletiforma. In the Sarmatian sediments of Poland, the presence of 10 cockle species was documented, two of which, *Plicatiforma praeplicata* and *Obsoletiforma vindobonense*, are common in the Badenian fauna.

The taxonomic composition of both studied families reflects, in a model way, the response of bivalves to environmental changes in the Middle Miocene of the Central Paratethys, but is not dependent on the type of bottom they inhabit.

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Suitability of the authigenic $^{10}Be/^{9}Be$ dating method for epicontinental basin sequences: A sedimentological and sequence-stratigraphic perspective

Establishing robust geochronological models for epicontinental basins poses a notoriously difficult problem due to several characteristics. The variability in connectivity of such basins to the World Ocean leads to frequent salinity changes and the extinction or endemism of planktonic taxa, complicating the application of biostratigraphy. Complex variations in base level and phases of subaerial deposition not only trigger sediment bypass or erosional events but also contribute to the incompleteness of the depositional record. The utilization of the authigenic $^{10}Be/^{9}Be$ dating method, which requires only a few grams of clay sediment as a dating sample, may offer a robust geochronological tool for epicontinental basins. This method is based on the ratio of atmospheric cosmogenic ^{10}Be delivered by precipitation and stable ^{9}Be provided to the sedimentary environment from rock weathering. The different origins of these nuclides result in paleoenvironmental variability of isotopic initial ratios, a factor that has not been thoroughly investigated in previous research. The ongoing project undertaken by the authors provides insight into how depositional processes and the sequence-stratigraphic context of a sampled succession affect the beryllium isotopic variability and the reliability of the obtained age models. The presented assumptions are based on case studies from Upper Miocene to Quaternary successions from the Pannonian Basin and Dacian Basin, as well as Holocene deltaic parasequences of the Po Plain.

The obtained results suggest that the stability of terrestrial ^{9}Be delivery to the environment is one of the crucial conditions to be met. Another important factor is a stable accommodation rate, which enables relatively rapid sediment burial without post-deposi

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New insights gained from zircon U-Pb dating of Miocene volcaniclastic deposits of the Sinj Basin (Dinaride Lake System, Croatia)

The intramontane basins of the Dinarides hosted a series of long - lived lakes during the Miocene, collectively known as the Dinarides Lake System. Sinj Basin is one of the best studied among them, providing valuable insights into the paleobiogeographic and paleoenvironmental evolution of the region. Its development was initiated by a prominent phase of extension which affected the whole orogen. However, the timing of the onset and duration of deposition is still a matter of debate, with consequences for tectonic interpretations.

The basin infill consists of a lower unit dominated by marls with coal intercalations and considerable terrigenous input, a middle unit composed of mostly unfossiliferous limy marls and marly limestones, and clayey carbonates with coal intercalations in the upper unit (Šušnjara & Sakač 1988). A chronostratigraphic framework was initially obtained in the NW part of the basin from paleomagnetic data collected along the 500 m thick Lučane section, calibrated by bulk Ar-Ar sanidine and biotite dating of intercalated volcaniclastic deposits (de Leeuw et al. 2010). The subsequent U-Pb dating of bauxites in the SE part of the basin demonstrated that lacustrine flooding across the Sinj Basin was diachronous (Brlek et al. 2021). This result was supported by a partial U-Pb re-dating of the Lučane section, highlighting the advantage of this dating technique over Ar-Ar dating in diagenetically altered volcaniclastic deposits.

The present study aims to provide new constraints on the evolution of the Sinj Basin, based on U-Pb zircon geochronology. Samples were collected from the Lučane section in the NW part of the basin, Crveni Klanac area in the SE part and from selected sites in its central part, around Glavice. First, the samples were crushed into a fine powder, which was subsequently washed using a gold pan in order to separate the heavy-mineral fraction. Individual zircon grains were handpicked using a binocular microscope. These were imaged for typology with a scanning electron microscope, before being mounted in epoxy resin. Subsequently, cathodoluminiscence images were produced on polished mounts to gain information about internal structures. U-Pb isotope analyses were obtained by means of laser ablationinductively coupled plasma mass spectrometry (LA–ICP–MS).

The obtained ages ranging between ~18 and ~15 Ma provide new constraints on the timing of initial lacustrine flooding, and together with the previously published literature, will aid in refining the timing of the Miocene extensional episode. In addition, a wide spectrum of detrital zircon ages was obtained, with distinct abundance peaks reflecting the pre-Miocene geodynamic history of the Dinarides. This work will serve as the basis for future U-Pb dating and correlation of Miocene lacustrine deposits of the Dinarides and Serbian Lake Systems.

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Characterizing the ~15.3 Ma explosive eruption: Insights from volcaniclastic deposits across the Pannonian Basin and the Dinarides

During the Neogene, repeated explosive eruptions of the Carpathian-Pannonian Region produced regionally spread volcaniclastic deposits. The volcanic record has become obscured due to erosion, tectonic activity, ongoing magmatism, and the deposition of younger sedimentary layers. To fully uncover the volcanic history of the source region, specifically the frequency and spatial distribution of individual volcanic events, a comprehensive approach is necessary. This approach should integrate fieldwork and various analytical techniques, applied to both proximal and distal records. To fully uncover the volcanic history of the source region, specifically the frequency and spatial distribution of individual volcanic events, a comprehensive approach is necessary.

At Mt. Požeška gora (SW Pannonian Basin), a ~15.3 Ma primary volcaniclastic record was previously recognized (Brlek et al., 2020), and tentatively correlated with other regionally spread contemporaneous volcaniclastic horizons from the Vienna Basin (Rybar et al. , 2019), the North Alpine Foreland Basin (Rocholl et al., 2018), as well as the Dinaride Lake System (de Leeuw et al., 2012). Coeval volcaniclastic deposits have not been recorded so far in the most complete Early to Middle Miocene volcaniclastic succession of the Bükkalja Volcanic Field in northern Hungary.

In our study, a multi-proxy approach is applied to newly discovered and well-preserved Mt. Požeška gora volcaniclastic succession, as well as on three additional volcaniclastic horizons variously distanced from Mt. Požeška Gora site (~100–300 km), to evaluate their correlativity.

Our study demonstrates that by utilizing data from the geochemistry of volcanic glass and minerals, alongside zircon petrochronology, we can establish a correlation between the volcaniclastic horizon of Mt. Požeška Gora and volcaniclastic deposits from Kuchyňa (Vienna Basin), Lučani (Sinj Basin), and Čučerje (Mt. Medvednica) localities.

These deposits are linked to a single eruption around 15.3 Ma from an as-yet unidentified source within the region. This newly established correlation positions the ~15.3 Ma volcaniclastic deposits as valuable marker beds for Neogene stratigraphy across the broader Pannonian Basin area.

This work is supported by the Croatian Science Foundation through project „Miocene syn-rift evolution of the North Croatian Basin (Carpathian-Pannonian Region): a multi-proxy approach, correlation and integration of sedimentary and volcanic record"(PYROSKA), (UIP-2019-04-7761).

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New updates on the Late Miocene land vertebrate faunas from the north of the Eastern Paratethys

The Late Miocene record of the continental vertebrates has a rich record in the north of the Eastern Paratethys. The territories of Romania, Moldova, Ukraine and Southern Russia provide with continental and partially marine deposits which contain also horizons of bone remains including all vertebrate groups. Age of these deposits have been largely dated by previous extensive studies from Sarmatian s.l. to Maeotian. In most cases, the ages of sites are poorly constrained, making the paleobiogeographic, -geographic, -environmental, and -climatic reconstructions and analyses in time and space extremaly difficult and vague.

Our new study aims to reassess the ages of the known sites and document new sites with vertebrate faunas using a multidisciplinary approach. Our field studies, we could not confidently relocate the earlier known sections and fossiliferous horizons (mostly those included in Lungu and Rzebik-Kowalska (2011)). Thanks to our new field observations and sampling, we have able to redescribed the sections and resampled for further analyses and studies. For more than ten sites of Bessarabian to Maeotian ages, a broad range of proxies such as sedimentological description, relative dating (magnetostratigraphy, micropaleontology, mollusc biostratigraphy, cosmogenic nuclides), and vertebrate paleontology has been applied.

The sections represent mostly fluvial deposits of the Balta Formation but they included also deposits from the shore and/or deltaic envirnments. These sediments provided mostly vertebrate assemblages. Mammalian biochronology and biostratigraphy of marine groups have been used to correlate the superpositions of the sites and faunas. Amphibian and reptilian assemblage allowed to reconstruct the paleoprecipitation values.

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Biostratigraphy and paleoecology of the middle Miocene deposits of Dilj gora Mt. (NE Croatia), Central Paratethys

The Middle Miocene sediments in NE Croatia, located within the North Croatian Basin (NCB) and paleogeographically affiliated with the southern margin of the Central Paratethys, were examined for their micropaleontological and petrographic characteristics. A sediment sample from Degman Hill on Dilj gora Mt. (point DV256) revealed a diverse microfossil assemblage, encompassing pteropods, foraminifera, ostracods, fish teeth, sponge spicules, and echinoderm fragments.

The sediment consists of fossiliferous silty marl, exhibiting a predominantly homogeneous texture occasionally enriched with organic matter. Mineral composition analysis identified quartz, feldspars, and phyllosilicates (mainly muscovite, sericite, and chlorite) alongside carbonate fragments embedded within a prevalent clayey-carbonate matrix. Planktonic bioclasts are abundant, while benthic forms occur sporadically.

Pteropods, planktonic gastropods from the family Cavoliniidae, colloquially termed "sea angels" or "sea butterflies," were classified into three morphotypes. Morphotype A, previously identified on Medvednica Mt., belongs to the genus *Vaginella* (aff. *V. austriaca* Kittl) (Bošnjak et al., 2017). Morphotypes B and C likely represent new species and a new genus. These gastropods typically exhibit 5-8 mm in length and 4-6 mm in width, appearing as flattened tests in carbonate coatings, molds, and impressions in the sediments.

The planktonic foraminiferal assemblage includes 19 species. Highly abundant species are *Globigerinoides subquadratus*, *Trilobatus trilobus*, and *T. immaturus*. Abundant species are *Tenuitella angustiumbilicata*, *T. munda* and *Globigerinoides obliquus*. *Trilobatus bisphaericus*, *Globigerinoides bolii*, *Trilobatus sacculifer*, *Globigerinita glutinata*, and others are low-abundant species. Rare occurrences have *Trilobatus sicanus* and *Globigerinella obesa*. Benthic foraminiferal assemblage with a total of 25 taxa is moderately diverse. *Siphonodosaria consobrina*, *S. script*a, *Melonis pompilioides*, and *Hansenica soldanii* are highly abundant species. The abundant species is *Uvigerina grilli*, whereas a low abundance has *Lenticulina inornata*, *Plectofrondicularia* sp., *Neugeborina longiscata*, *Fontbotia wuellerstorfi*, *Buchneriana buchneri* and *Guttulina communis*. The plankton benthos ratio is 90:10.

Overall, 15 ostracod taxa of deep-marine, mostly infra-neritic and bathyal species, and the shallow-water species were present in the sample. *Bythocypris lucida, Krithe* sp., *Cytherella* cf. *vulgat*a, and *Argilloecia* sp. have rare occurrences, while species *Aurila* cf. *punctata*, *Aurila* sp., *Butonia dartonensis*, *Cytheropteron* sp., *Eucytherura* sp., *Grinionesis haidingeri*, *Calistocythere* cf. *karpatiensis*, *Leptocythere* sp., *Neocytherideis* cf. *linearis*, *Paracytherois* sp., *Saida* sp., and *Semycytherura* sp., have very few.

Rich assemblages of siliceous sponge spicules that belong to different families are also found in the sample.

The composition of the assemblage and the common co-occurrence of the *Trilobatus bisphaericus* and T*rilobatus sicanus* are characteristic of the planktonic foraminiferal MMi4a Zone (Lirer et al., 2019) and M5b

Zone (Raffi et al., 2020) which correspond to lower Badenenian. Most of the determined ostracod species are known from the lower Badenian deposits of the NCB, and seven species from our sample are known from the Karpatian of Central Paratethys (Zorn, 2003). The assemblages of siliceous sponge spicules are similar to those described from the Karpatian of the Carpathian Foredeep in Moravia (Pisera and Hladilova, 2003).

This rich and diverse lower Badenian microfossil assemblage, typical of warm to subtropical seas, implies an open connection of the southern margin of the Central Paratethys with the Mediterranean and, thus, indirectly with the Indian Ocean. Petrographic analysis of the marl and a very high percentage of the planktonic foraminifera indicate sediment deposition within a deeper marine environment, with occasional fine-grained detritus from land.

Warm-water-preferred planktonic gastropods and spinose planktonic foraminifera, such as Trilobatus and *Globigerinoides*, indicate a warm sea surface and well-stratified water column. However, the benthic foraminiferal fauna dominated by infaunal species (*Siphonodosaria*, *Melonis*, *Hansenica*, *Uvigerina*) suggests a low oxygen microhabitat but rich in organic matter and cool bottom water.

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Assessing the preservation of spatangoid echinoids in hypoxic environments (Vienna Basin, Miocene, Central Paratethys)

Exceptional preservation of macrobenthic invertebrates with articulated remains is frequently explained by episodic rapid burial events or by onset of anoxia. Here, we assess whether macrobenthic assemblages dominated by the shallow-burrowing spatangoid echinoid Lovenia that inhabited bathyal environments during the Early Miocene and are preserved in the so-called Schlier-type sediments in the Vienna Basin conform to these scenarios. Echinoids occur in three taphofacies types that are compositionally similar but differ in preservation, size, and species diversity, including (1) dispersed or clustered, frequently complete echinoid tests occurring in homogeneous or partially-laminated diatomaceous clays, (2) pavements with densely-packed echinoid tests that form pavements capped by mm-thick sands, with intermediate frequency of intact tests with spines, and (3) cm-thick sandy skeletal lags formed by well-sorted echinoid test and plate fragments. Echinoid tests are best preserved in the homogeneous taphofacies with high abundance of hypoxia-tolerant benthic foraminifers and with vestiges of lamination formed by Thalassionema or Coscinodiscus-dominated diatom assemblages, indicating that (1) burial of echinoids below the mixed layer was induced by terrigenous particles settling from suspension and by diatom blooms and dumps rapidly exported to the seafloor rather than by their sudden burial by thicker event deposits, (2) sediment mixing rate was slow and patchy as the diatomaceous mats were not eliminated by echinoid and crustacean burrows (Scolicia and Thalassinoides), and (3) high frequencies of complete tests and test fragments with spines or with dislocated plates indicate that disarticulation and fragmentation rates in sediment or at the sediment-water interface were very slow. Echinoid concentrations in pavements probably reflect primary aggregations that were only later modulated by winnowing as the homogeneous or partially-laminated taphofacies are shell-poor but compositionally do not differ from pavements. Hypoxia and fast sediment accumulation of Schlier-type deposits driven by suspension-fallout of diatoms and clastic sediment thus led to an unusual census-like preservation of weakly time-averaged assemblages (contrasting with complex preservation pathways of fossil assemblages in well-oxygenated environments subjected to bioturbation).